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Northern Great Plains Resource Program

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NORTHERN GREAT PLAINS RESOURCE PROGRAM

WATER WORK GROUP REPORT

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Analyzes surface water resources of the Upper Missouri River Main Stem and Yellowstone Basin with a brief analysis of the ground water resources in Montana and Wyoming. Constraints to water resource development are analyzed along with historical resource development, water availability above present uses, cost of delivery and water availability for alternative levels of coal development in Wyoming, Montana, and North Dakota. A separate report is included on in-stream needs. It projects amounts of water that should be left in streams to maintain present riparian and aquatic habitats. It assumes that there is a need for maintaining fluctuating annual flows rather than traditional minimum level flows. A separate report is included on the wild and scenic river recreational values of Upper Missouri and Yellowstone Basin streams that may be affected by coal development. This analyzes the relative wild and scenic river values of the various streams and addresses potential impacts upon them if water were used for coal conversion facilities.

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NORTHERN GREAT PLAINS RESOURCES PROGRAM

REPORT OF THE WORK GROUP ON WATER

December 1974

THIS REPORT WAS PREPARED PURSUANT TO A DIRECTIVE DATED OCT. 23, 1973, FROM THE PROGRAM MANAGER, NORTHERN GREAT PLAINS RESOURCES PROGRAM. PUBLICATION OF THE FINDINGS AND RECOMMENDATIONS HEREIN SHOULD NOT BE CONSTRUED AS REPRESENTING EITHER THE APPROVAL OR DISAPPROVAL OF THE SECRETARY OF THE INTERIOR, THE SECRETARY OF AGRICULTURE, THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY, OR THE STATES OF MONTANA, NEBRASKA, NORTH DAKOTA, SOUTH DAKOTA, AND WYOMING. THE PURPOSE OF THIS REPORT IS TO PROVIDE INFORMATION AND ASSISTANCE TO THE PROGRAM MANAGEMENT TEAM IN THE PREPARATION OF THE DRAFT INTERIM REPORT ON THE NORTHERN GREAT PLAINS RESOURCES PROGRAM. THE PROGRAM MANAGEMENT TEAM IS RELEASING THIS DRAFT FOR PUBLIC USE WITHOUT CORRECTING INCONSISTENCIES OR REWRITING BECAUSE THE DELAY REQUIRED TO ACCOMPLISH THIS TASK WOULD DELAY THE TIMELY ISSUANCE OF THE REPORTS.

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NORTHERN GREAT PLAINS RESOURCE PROGRAM

WORK GROUP (C) WATER REPORT

PREFACE

The task of the Water Work Group in the NGPRP was to determine the potential role of water in development of the coal in the northern great plains region, and the effects such development would have on the water and related resources of the region. The elements of this task included: (1) an inventory of the region's water resources including present water availability and quality, (2) an analysis of the constraints on water resource development, (3) a depiction of potential water development associated with various levels of coal development at various times in the future, (4) a determination of the impacts and effects of such potential development, (5) the findings and conclusions of the water work group, and (6) identification of further needs for information to assure sound decisions about resource use. These six topics are treated in the chapters which follow.

The lead agency for the Water Work Group was the U.S. Bureau of Reclamation. The following three pages list the work group members and also the members of the four subgroups.

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NORTHERN GREAT PLAINS RESOURCE PROGRAM

WORK GROUP (C) WATER REPORT

SUMMARY

The water work group of the Northern Great Plains Resource Program was charged with the responsibility of 1) preparing a regional profile report consisting of water quantity, quality, and uses in the Northern Great Plains (NGP); 2) preparing a report on the constraints of utilizing water in coal conversion in the NGP; 3) determining alternative water supplies sufficient for hypothetical levels of coal development; and 4) the impact of development on water quantity and quality for three hypothetical coal development scenarios.

Future water needs were based on the assumption that all coal conversion facilities would use wet cooling towers. If dry towers were to be constructed, the water impacts would be less than those stated in this report, and the potential for pollution would be less and would be different. A zero effluent could create solids disposal problems rather than surface water quality impacts. The extent and impact of such waste disposal was not studied.

Water supplies for potential use in the Fort Union-Powder Basin Coal Region have been estimated. Only those waters in excess of the estimated 1970 use have been considered - in an attempt to avoid conflict with current water users. The water to be discussed may be used for any type of new development and will, to that extent, be in competition with all future water needs which require diversion. Valid rights which are not presently being exercised are not reflected in streamflow records, and these rights may have priority over new developments. The quantities of water that may be claimed under such rights are believed to be small.

Within the coal region proper, water is quite limited because of the low amount of precipitation received. Most of the water available is at distant but more centralized locations on larger rivers and storage locations. If development is kept to a minimum, the coal region might supply sufficient local water provided local storage sites are constructed. Extensive demand for water might necessitate large and long aqueducts to connect the points of availability with the points of need or an expanded storage system.

Deep ground water is known to underlie much of the coal region. Current information indicates that a large volume of ground water is present and it may represent a significant resource. It is believed that deep ground water can be obtained in most locations in limited amounts and, in some instances, may provide an adequate supply for coal conversion. Whether there is a potential for supplying substantial amounts of ground water depends on ability and success of recovery, and insufficient data are available to provide such assessments now. Further explorations and analyses will be required before judgments on recovery, recharge, and chemical quality can be reached.

Shallow ground waters, frequently adequate for livestock and rural domestic needs, are wholly insufficient to provide industrial water.

Surface waters within the region are required to support the existing levels of development, emerging needs for development in progress, and future needs of valid prior water rights which have not been perfected. Any unused and unappropriated waters in excess of the aforementioned is a measure of surplus water potentially available for future uses. Surface waters within each State belong to the public and the Indians on the reservations. Each State has an administrative procedure to consider water use applications and authority to grant permits. Indian water rights have not, as yet, been fully determined.

The Doctrine of Appropriation is followed in the States involved with the Northern Great Plains Resource Program study. It predicates that "first in time is first in right" and streams are adjudicated on that basis. Issuance of a permit is for use of the water only, rather than ownership; ownership resides in the public.

There is no agreement between the States on sharing of the water except under the Yellowstone River Compact affecting four interstate tributaries to the Yellowstone River where surplus waters are to be shared on a percentage basis between Wyoming and Montana. Surplus waters will be those remaining after all rights as of January 1, 1950, have been, or may in the future be, satisfied to the extent physically and economically possible. When this point is eventually reached, the remainder of the unused and unappropriated water will be allocated under Article V as follows:

Interstate Tributary	State Entitlement to Surplus Water In Percent Wyoming	 Montana
Clarks Fork Yellowstone	60	40
Bighorn	80	20
Tongue	40	60
Powder	42	58

In the Yellowstone and Upper Missouri drainage above their junction there are about 2.6 million acres of land under irrigation farming. An estimated 4.5 million acre-feet of water is now being consumed annually above Lake Sakakawea for all purposes. The 8.8 million acre-feet and 7.3 million acre-feet of annual average flow in the Yellowstone and Missouri, respectively, as measured at their juncture, are representative of the approximate remaining flow at the 1970 level of development. Only these remaining flows are under study. In a dry year the Yellowstone drops toward 4 million acre-feet and has climbed above 15 million acre-feet in a single wet year. The Missouri would have similar variances from average except that Fort Peck Reservoir allows considerable smoothing of annual flows.

Conflicts between agriculture and industry until now have been minimal, although industry has purchased a number of ranches, particularly in Wyoming, to obtain water rights. Serious and extensive conflicts can be anticipated over intended future uses of the water resources. On a regional basis there appears to be adequate water to meet future needs of both agriculture and industry, along with municipal needs. However, there are some areas of water deficiency which will require new storage if the needs are to be met. This is especially true within the Yellowstone Basin.

In addition to the future needs for water by agriculture, industry, and municipalities, the States have important riverine ecosystems. If existing aquatic systems are to be preserved, it will significantly reduce the amount of water available for other uses or shift the points of available water supply from the Yellowstone and other tributaries to more downstream locations such as the Missouri River where instream flow requirements are less acute. It has been estimated that preservation of the aquatic system by maintaining instream flow requirements will reduce potential water availability within Yellowstone Basin from 3 million to under 2 million acre-feet annually.

Outlook for future federally sponsored irrigation development is not bright. For example, under existing project formulation criteria, there are essentially no units which meet federally funded economic justification within the Yellowstone Basin. There will doubtless be some amount of private and State-assisted irrigation in the future, but the extent is not predictable. While there are hundreds of thousands of acres of land classed arable, the distance from and height above the rivers pose considerable constraint against much of it becoming irrigable and thus justifiable for economic development. However, increasing demand for farm products with resulting increased prices may make more of the arable land economical to irrigate.

Allocations under provision of Yellowstone River Basin Compact will enable Wyoming to claim between 2 and 3 million acre-feet on an annual average from the Clarks Fork Yellowstone River, Bighorn River, Tongue River, and Powder River. Montana is entitled to the remainder as well as the Yellowstone River proper and all other tributaries.

Studies accomplished in NGPRP indicate that the most environmentally acceptable approach in most cases would be to leave water belonging to both States in the river system as far downstream as possible.

Water for Wyoming can be delivered at the approximate same cost from a diversion at Miles City, Montana, as from Hardin, Montana, because of better alignment and shorter distance.

Article X of the Yellowstone Compact deserves special consideration. According to the article, export of water from the Yellowstone Drainage Basin can occur only with the concurrence of the signatory States - Montana, Wyoming, and North Dakota. Two plants outside of the Yellowstone Basin in Wyoming were included in the studies. While water for these two plants was assumed to come from the Yellowstone Basin in the surface water availability studies, it must be remembered that such a proposal by Wyoming would require the approval of Montana and North Dakota. It was recognized that supply from the Yellowstone represents only one alternative among several potential methods of supplying these plants. Other alternatives include the Green River, Oahe Reservoir, deep ground water, and use of water saving technologies. Additional study and cooperation among the States will be necessary before a "best" supply alternative is identified for plants outside the basin.

Indian water rights are those which the courts have declared to be reserved for the use of the Indians on reservations. There is some question as to quantification of these rights, but the United States Supreme Court case of Winters v. United States, decided January 6, 1908, 207 U.S. 564, indicates that the reserved waters could be used for "agriculture and the arts of civilization." The Court stated that the Government had the power to reserve the waters and exempt them from appropriation under State laws.

Indian tribes of the Northern Great Plains claim a legal right to utilize waters for beneficial use which flow through, originate on, or are adjacent to their reservations. At the present time the Bureau of Indian Affairs and the tribes are actively exploring present and potential uses of water on Indian reservations, including the location of possible storage sites and possibilities for future development.

All five States recognize the right of Indians to whatever water can be put to use on reservation lands. None of them agrees with the broader and more extensive claims to water advocated by many of the Indian tribes of the Northern Great Plains. Wyoming contends that Indian rights are valid for irrigation purposes when such need is properly established and that the State should administer all water in accord with its water laws to prevent conflicts which might arise between existing agriculture and potential use of Indian water. Montana policy will be established in administering its new Water Code, and it is anticipated that the State will recognize equality of Indian water rights. Indian water rights may eventually have to be quantified through court procedures.

Studies in the Northern Great Plains Resource Program have assumed a depletion of water for the future development of 50,000 acres of irrigation on Wind River Reservation in Wyoming. Early studies of land and water indicated that this amount would meet the maximum level of potential development there. Detailed studies now in progress may require different depletions, but an estimate of upstream effects was necessary to establish the approximate amounts of water that would be available for the Fort Union-Powder Basin coal region. No adjustments to streamflow were made for other potential Indian reservation developments.

Ample water is available from the Missouri River to meet projected needs. From Fort Peck downstream, no additional storage will be needed, but extensive irrigation development in the upper reaches could require new storage. Water also appears to be available at all plant locations in the Yellowstone Basin in the three scenarios, although suggested instream needs are not always met. If plant locations are on Indian land, the use of available water is assured. Water for other Indian development is available and as future depletions for additional Indian developments occur, replacement water can be made available to other users if instream flow requirements are further deprived or if additional storage facilities are built.

Many of the objectives of the Water Work Group were achieved. Some of the important objectives and our general observations are these:

1. Wild, scenic, and recreation classifications were undertaken for the important rivers within the region. The purpose was to avoid such areas, and it appears that conflicts will be negligible or minor under all scenario situations.

2. Instream flow requirements were explored. While accuracy of the instream flow values needs verification through continued detailed biological and water quality studies, the preliminary estimates are assumed in this study to sustain the existing aquatic resources and associated riparian habitat. The instream need estimates are based on quantity alone. Water quality was assumed to remain unchanged. The suggested instream needs were largely but not entirely accommodated in the studies conducted. These needs are not consistent with Article V of the Yellowstone River Compact. They were employed in Northern Great Plains Resource Program water supply operation studies to demonstrate water availability considered to be unencumbered by major environmental concerns.

The Montana Water Use Act of July 1, 1973, recognizes preservation of flows and water quality for fish and wildlife as a beneficial use and provides that waters can be reserved for that purpose and for the purpose of future beneficial uses. Montana is the only Northern Great Plains State to recognize fish and wildlife flow needs as a beneficial use. It is a concept not widely recognized in the water laws of western States, and whether its legality can be sustained in the courts is yet to be tested.

3. The impacts of coal development on the water quality of the Northern Great Plains have received considerable attention. The purpose of the water quality analyses was to develop a profile of existing water quality and to predict how current water quality might change as a result of the levels of development shown in the scenarios.

Detailed studies would be required to predict the exact impact of development including precise location, specific coal characteristics, source of water, monthly distribution of flows and return flows, scrubbing devices, types of pH and scale controls, etc. However, most problem areas can be predicted by analyzing Total Dissolved Solids (TDS) and assuming salt balance; dissolved oxygen levels can be estimated for streams receiving municipal wastes by utilizing Streeter-Phelps equation and approximating existing oxygen levels.

A monthly analysis of water quality impacts, both quantitatively and qualitatively, has been prepared. The conclusions reached were that TDS will increase but will not prohibit beneficial uses. In the areas where TDS increases are potentially damaging, problems may be avoided or corrected by eliminating return flow. The effects of short-term low flows were not analyzed.

Population increases in the region could require upgraded sewage treatment facilities. Sheridan, Wyoming, for example would require more intensive and higher cost sewage treatment facilities to prevent pollution of Goose Creek. For smaller communities at all locations or larger communities on the main tributary streams, secondary treatment will probably suffice.

Increases in irrigation and other noncoal-related water use will have water quality impacts, but predictions in this area are not within the scope of this analysis.

4. The probable effects of strip mining and plant effluents on shallow ground waters were examined. Preliminary conclusions are that water tables within 3 to 4 miles of a mine are expected to lower. Upon reclaiming, the water tables will generally recover to elevations near their predisturbed condition. The temporary interruption will persist from 10 to 15 years. In most cases, deeper wells can provide water of equivalent volume and quality during the period of disruption at a much higher cost.

   Lowered water tables during the period of disruption will be from less than 10 feet near the perimeter of the cone of influence to as much as 200 or even 300 feet in case of deep strip mines underlying thick overburden.

   Where mines are located in ground-water recharge areas there may be potential for contamination of shallow aquifers. Preventing this might require special precautions or measures such as lining the pits with an impermeable membrane, or providing evaporation ponds for mine and spoil pile leachates.

5. Surface water can be made available through aqueducts to each potential development site in each scenario; however, to do so would mean in a few instances that suggested instream needs could not be fully met. Impacts to the aquatic resources range from minimal in some areas to severe in other areas depending on the scenario design addressed. Impacts on land resources would be limited to significant temporary, and minor long-time, effects of buried aqueducts. Some 600 miles of large-diameter aqueducts would be required to divert the 1.5 million acre-feet required for the Extensive Development.

   Water requirements for Most Probable Development total about 730,000 acre-feet annually. This plan can be served mostly by aqueducts, but some alternatives call for two new reservoirs and deep-aquifer ground-water development.

   The design analyzed for the Base Development incorporated new storage, but reduced the need for aqueducts to about 80 miles of small pipelines. The reservoirs analyzed would be located on Powder River and Tongue River where substantial loss of wildlife habitat could be expected. Only 124,000 acre-feet of water are required for the Base Forecast.

5

6. Coal development is not a large segment of the total projected depletion above Sioux City; but as an indication of such effect, the navigation season would be shortened about 3 weeks and generation would be reduced by an estimated 254 million kilowatt-hours as a result of depletions due to coal development in the Extensive Development scenario. Most likely development would cut the above reductions by one-half.

7. Cost of providing surface water has been computed, using 8 percent interest, 40-year repayment, and 8 mills per kilowatt-hour for pumping energy. Also investigated were lower and higher interest rates and pumping energy costs and longer and shorter repayment periods. Water costs at each facility were derived in each scenario for two or more choices or alternatives under that scenario; and, to provide additional cost information, plants north and south of Gillette were examined by transposing locations.

Approximate Average Annual Cost of Water Delivered

(Dollars Per Acre-Foot)

State	Scenario	Choices		
		1	2	3
North Dakota	Base Forecast	38	38	
	Most Probable	96	86	
	Extensive Development	80	83	80
Montana	Base Forecast	71	240	
	Most Probable	143	159	
	Extensive Development	104	103	111
Wyoming	Base Forecast	115	325	
	Most Probable	230	141	
	Extensive Development	226	263	261

Deep ground water may be cheaper for some locations provided it is present in required quantities, economically recoverable, and of sufficient quality. Preliminary estimates indicate such ground water may cost around $50 to $60 per acre-foot.

If improved technology reduces the amount of water required in coal conversion processes, the cost per acre-foot of water provided may rise, but the total cost of supplying water would drop.

REGIONAL WATER PROFILE

Study Area

The Northern Great Plains coal region, shown in Figure 1, is basically comprised of the Powder River Basin and Williston Basin (Fort Union area) and is located within the eastern third of Montana, the western half of North Dakota, the northeastern quarter of Wyoming, and the northwestern quarter of South Dakota. The study area considered by the Water Work Group includes not only the coal region but also part or all of the drainage basins of several of the rivers entering or traversing the region or adjacent to it. These river basins and subbasins are shown on plates 3 and 4 and are all part of the drainage area of the Missouri River above Sioux City, Iowa. The major rivers are: the Yellowstone River and its principal tributaries - the Clarks Fork Yellowstone, Wind-Bighorn, Tongue, and Powder Rivers; and the Upper Missouri River and its western Dakota tributaries - Little Missouri, Knife, Heart, Cannonball, and Grand Rivers. Also considered, as a possible source of import water is the Green River, a tributary of the Colorado River.

The topography of the study area varies from level or gently rolling plains to the rugged mountains along the Continental Divide, with elevations ranging from over 13,000 feet in the mountains to about 1,600 feet at Lake Oahe. Major mountainous areas in the study area are the Bighorn and Pryor Mountains adjacent to the Bighorn River and the Wind River, and Absaroka and Wind River Ranges along the western side of the Wind-Bighorn and Clarks Fork Basins. Throughout the plains portion there are numerous small hilly areas, buttes and hogbacks, and some badlands and canyon areas.

Although total annual precipitation in the mountainous portions of the study area ranges up to 50 inches, the annual precipitation over the coal region itself averages only about 14 inches. Of this, about 3 to 4 inches derive from snowfall which averages about 40 inches. Consumptive demand of vegetation (the water vegetation would use if it were available) in the area is about 26 inches. Surface runoff averages less than 5 percent, and practically none of the direct rainfall or snowmelt becomes part of the ground-water system. Underlying the coal region is a large ground-water resource 4,000 to 12,000 feet below the land surface. It appears to have limited recharge (most recharge occurs in the Black Hills and along the flanks of the Bighorn Mountains), rather poor quality, and may be considered unproven and untested. The potential may be promising, especially for small to medium volumes of water; but if long-range water supplies of large quantities, good chemical qualities, and known reliability are to be made available for coal conversion now, the water will probably have to be obtained from rivers originating elsewhere and flowing through or past the coal region.

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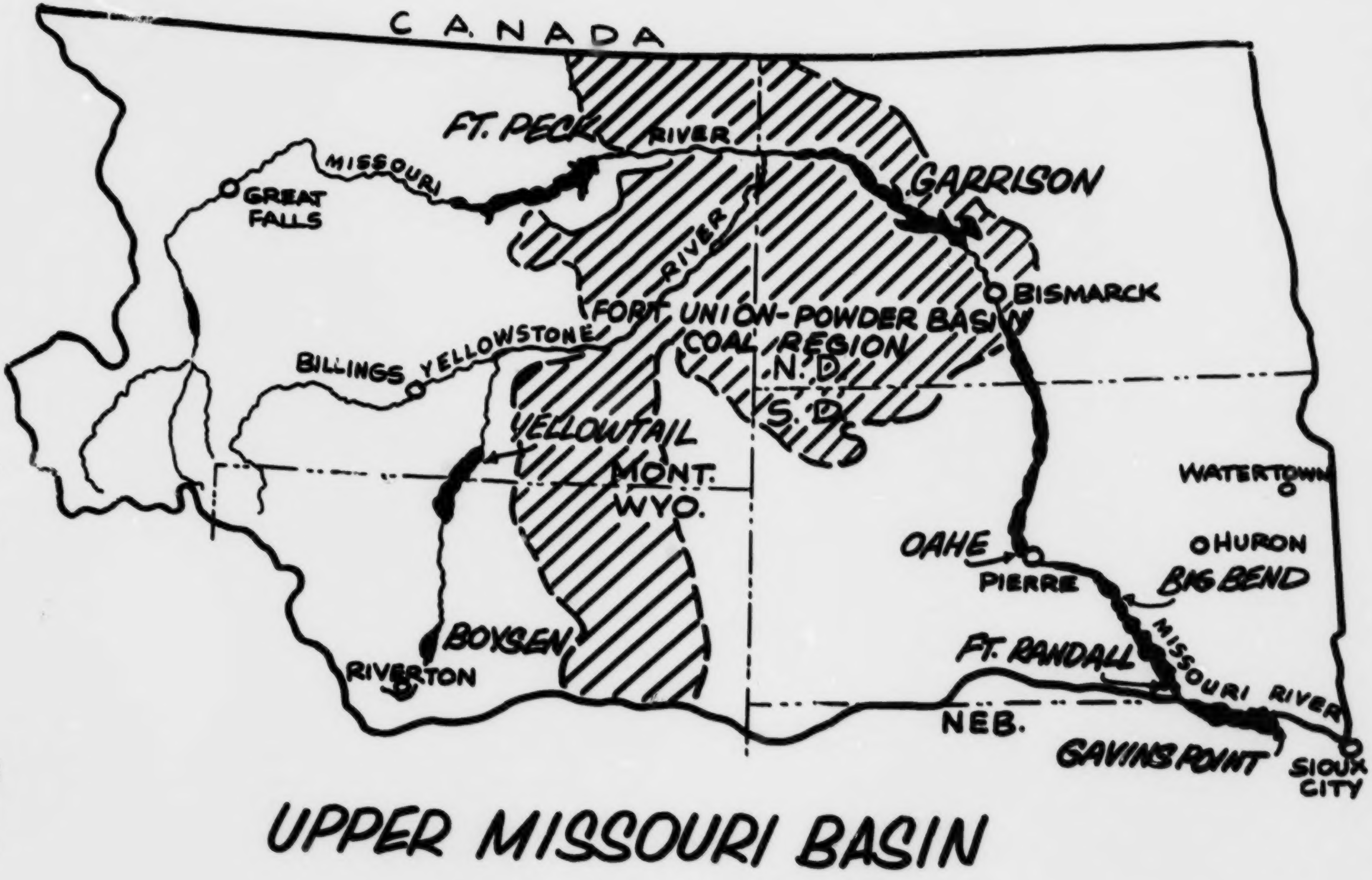
CANADA
FT. PECK
RIVER
MISSOURI
GREAT FALLS
GARRISON
RIVER
BISMARCK
FORT UNION-POWDER BASIN
COAL REGION
N.D.
S.D.
BILLINGS
YELLOWSTONE
YELLOWTAIL
MONT.
WYO.
WATERTOWN
HURON
OAHE
PIERRE
BIG BEND
MISSOURI RIVER
FT. RANDALL
BOYSEN
RIVERTON
NEB.
GAVINS POINT
SIOUX CITY
UPPER MISSOURI BASIN

Figure 1

Surface Water

Quantity

The Missouri River Basin includes all or parts of ten States. It is convenient to think in terms of the Upper Basin and Lower Basin. Sioux City, Iowa, is considered to be the point where the dry upstream States meets the wet downstream States. Below Sioux City lies most of the flood control, much of the hydropower market, and all of the navigation. Above Sioux City are the six main-stem reservoirs and powerplants which provide downstream services. The Upper Basin envelops the Fort Union-Powder Basin Coal Region and contains the Northern Great Plains.

Most of the water which passes Sioux City originates in the mountainous regions of Montana and Wyoming. Average annual flow at Sioux City corrected to 1970 level of development is 21,821,000 acre-feet. Accretions below Sioux City averages 31,429,000 acre-feet annually and streamflow totals 53,250,000 acre-feet at Hermann, Missouri, near the mouth. Drainage area is 314,600 square miles at Sioux City and 528,200 square miles at Hermann.

To help smooth out the variable streamflow, the six main-stem reservoirs provide 40,665,000 acre-feet of carryover storage and 11,600,000 acre-feet of seasonal joint-use storage. In addition, there are 4,835,000 acre-feet of empty space for exclusive flood control and 17,630,000 acre-feet of inactive space to provide power head and to accommodate future sedimentation. The total storage of main-stem reservoirs as of 1970 was 74,730,000 acre-feet.

The 1944 Flood Control Act which authorized the Pick-Sloan Missouri Basin Program provides that:

> "The use for navigation . . . of waters arising in States lying wholly or partly west of the Ninety-eighth Meridian shall be only such use as does not conflict with any beneficial use, present or future . . . of such waters for domestic, municipal, stock water, irrigation, mining, or industrial purposes."

A recent study made by Missouri River Division Office, Corps of Engineers, found that if it becomes necessary to subordinate navigation to serve all beneficial consumptive uses, that 9.5 million acre-feet (above current /1974/ uses) could be made available annually.

Streamflow within the coal region itself is limited to the seasonal surpluses above existing uses within each of the smaller tributaries. When snowmelt and rainfall are deficient, water supply is inadequate to meet current needs. Even with seasonal deficiencies, however, there are significant amounts of unused waters within the Fort Union Coal region which can be made available for additional future uses within the area. The limiting physical factors are the amounts of new storage which can be constructed and the extent of surplus waters which can be impounded and controlled; development could also be limited by social, environmental, and economic factors.

Unconsumed water within the Yellowstone River Basin, which is essentially an approximation of water in excess of current use, averages about 8.8 million acre-feet annually, when corrected to the 1970 level of development and considered over a long time period (1898-1972). The upper reaches of the Yellowstone River and its minor tributaries produce more than half of the water supply, while the major tributaries contribute about 4.0 million acre-feet. The major tributaries are considered to be the four northward flowing tributaries which flow out of Wyoming and which comprise the Yellowstone Compact. These four tributaries, Clarks Fork Yellowstone, Wind-Bighorn, Tongue, and Powder Rivers, will eventually have their surplus flow allocated between Wyoming and Montana.

There is a large amount of water in the Missouri River between Fort Peck Reservoir in Montana and Lake Sakakawea in North Dakota and most of it is in excess of current needs. Long-time average annual outflow from Fort Peck is 6,838,000 acre-feet and increases to 7,258,000 acre-feet at the Montana-North Dakota line which is but a short distance above the confluence of the Yellowstone and Missouri Rivers. Adequate operational control is afforded by Fort Peck Reservoir, capacity 18,900,000 acre-feet, to provide substantial water supplies to any new uses which might develop in that vicinity.

Most of the streamflow of western Dakota tributaries is unregulated and highly variable. Considerable use is made of the water supplies. Consequently, there is not a large potential water resource in the plains streams that can be developed, but small to moderate amounts could be supplied for new uses if storage reservoirs were constructed.

The tabulation which follows is intended to illustrate the approximate quantities of unconsumed waters available. Except for minor downward revisions to be expected with a precise updating of water right filings and applications, the quantities represent essentially the remaining water supplies after 1970 which can be considered for development in meeting the needs of all future uses.

River and Location	Maximum Annual Flow (Acre-Feet)	Critical Year Flow (Acre-Feet)	Average Annual Flow (Acre-Feet)
Yellowstone Basin:			
Clarks Fork Yellowstone	1,124,000	538,000	767,000
Wind-Bighorn near mouth	3,607,000	1,429,000	2,550,000
Tongue near mouth	569,000	32,000	304,000
Powder near mouth	1,154,000	43,000	416,000
Yellowstone near Sidney	12,690,000	3,720,000	8,800,000
Upper Missouri Basin:			
Missouri near North Dakota border	-	-	7,276,000
Western Dakota Tributaries:			
Little Missouri near mouth	1,294,000	35,000	390,000
Knife near mouth	315,000	3,000	118,000
Heart near mouth	515,000	17,000	154,000
Cannonball near mouth	711,000	1,000	149,000
Grand near mouth	712,000	9,000	156,000
Upper Missouri Basin:			
Missouri River at Lake Sakakawea	-	-	16,952,000
Upper Missouri Basin:			
Missouri River at Oahe Reservoir	-	-	18,525,000

None of the waters in the Fort Union region are covered by interstate compacts except four tributaries of Yellowstone River which flow from Wyoming into Montana. Thus, it can be assumed that all waters in the region are available for use by the States in the region, and any sharing required by the Yellowstone River Compact relates only to Wyoming and Montana. The Forest Service is presently quantifying the volumes of water which they are claiming under the "reservation doctrine" and those quantities will be minor. Indian Tribes are in the process of making studies which will lead to quantification of their claims, and these will range from significant to large.

Storage reservoirs within the coal region have been developed over the years. Most were constructed to support irrigation development, but Bighorn, Fort Peck, and Sakakawea Reservoirs were built for additional purposes. Table 1 shows existing reservoirs associated with the coal region.

Quality of Surface Waters

The quality of a body of water can be determined in a variety of ways, and the way chosen is usually related to the use that is to be made of the water. Water quality can be measured by its physical characteristics such as pH, temperature, color, etc.; by its chemical characteristics such as salinity, nutrients, trace elements, etc.; and by its biological characteristics such as fishery, bacteria, aquatic ecosystem, etc.

Present water quality in the Northern Great Plains study area is measured only at selected locations and for selected parameters. In general most current water quality data are from USGS, EPA, and State water quality sampling stations. These data are largely physical and chemical descriptions of water quality. State and Federal Fish and Game Departments have collected biological data as well, though their data are largely confined to fishery data. While there is a definite need for additional baseline water quality data, certain generalizations can be made with the existing data.

The Water Quality Subgroup Report gives current water quality profiles for river basins in the NGPRP study area. For the profiles a total of 52 water quality stations were examined. The existing data generally exhibits a high degree of uniformity. From the information in these profiles it can be generally concluded that the water quality of the streams in the Northern Great Plains is fair to good. This judgment, however, must be tempered with the realization that pertinent water quality information often is not available to adequately describe current water quality.

Much of the water coming into the Fort Union coal region originates at high elevations from snowpack. Warming in May and June produces the melt and provides high rates of runoff. In June, the wettest month, rain can frequently add substantial water to that from melting snow and produce flood conditions. The western Dakota tributaries lie entirely on the high plains and their flows are derived mainly from rainfall. Infrequently they accumulate deep snows and experience early runoff in March or April. Some tributaries drain soils derived from shales, and quality of the resulting streamflow is locally poor until such flows become mixed with water of better quality which originates outside the Fort Union coal region.

Water of excellent quality is generally found at the head of streams near the mountain divides. Degradation of the chemical, physical, and biological quality is evident as streams progress downward, resulting from hydrologic, geologic, and man-made influences. Except in a few localized areas the quality is satisfactory for irrigation, livestock

Table 1

Existing Major Reservoirs in Fort Union Coal Region

River Basin	Reservoir	Storage in Thousand Acre-Feet				Uses
		Inactive and Dead	Active	Flood Space	Total	
Missouri	Fort Peck	4,300	10,900	3,700	18,900	R, FC, Irr., N, P, M, I
	Lake Sakakawea	5,000	13,400	5,800	24,200	R, FC, Irr., N, P, M, I
	Oahe Reservoir	5,500	13,700	4,300	23,500	
Milk	Nelson	18.7	66.8	-	85.5	R, Irr.
Clarks Fork	Cooney	0	24.4	-	24.4	R, Irr.
Wind-Bighorn	Bull Lake	0.7	151.8	-	152.5	R, Irr.
	Pilot Butte	5.4	31.5	-	36.9	P, Irr.
	Boysen	252.1	549.9	150.4	952.4	R, FC, Irr., P, M, I
	Anchor	0.1	17.3	-	17.4	Irr.
	Buffalo Bill	48.2	373.1	-	421.3	R, Irr., P.
	Bighorn	502.3	613.7	259.0	1,375.0	R, FC, Irr., P, M, I
	Upper Sunshine	1.0	52.0	-	53.0	Irr., S, D, I
	Lower Sunshine	1.9	54.9	-	56.8	Irr., D, S, P, I
Powder	Lake DeSmet	0	239.0	-	239.0	R, Future Industry
Tongue	Tongue Reservoir	5.9	68.0	-	73.9	R, Irr., M, I
Heart	Dickinson	1.2	5.5	-	6.7	R, Irr., M, I
	Heart Butte	6.8	69.0	150.5	226.3	R, FC, Irr., M, I
Grand	Bowman-Haley	4.3	15.8	72.9	93.0	R, FC, M, I
	Shadehill	58.2	30.0	269.6	357.8	R, FC, Irr.

R - Recreation FC - Flood Control Irr. - Irrigation N - Navigation P - Power M - Municipal I - Industrial
S - Stockwater D - Domestic

Table 2

Water Quality Summary - Water
Work Group (C) Study Area

	Temp C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb ug/l	Cu ug/l	Hg ug/l	F ug/l	Se ug/l	Al ug/l	B ug/l	Zn ug/l
Bighorn River at Bighorn, Montana																		
No. of samples	81			275	343	32	47							70			57	
Maximum value	27.2			8.5	23000	836	21100							700			270	
Minimum value	0.0			7.0	612	471	42							200			30	
Mean value	112.8			7.7	4249	608	4088							400			133.5	
Period of record	59-73			59-73	49-73	68-73	59-71							59-73			49-73	
Tongue River at Miles City, Montana																		
No. of samples	85			236	260	34		11						62			50	
Maximum value	29.4			8.8	4130	816		.1						800			1250	
Minimum value	0.0			6.9	16	262		.01						20			10	
Mean value	10.5			7.9	594	560		.04						361			137.3	
Period of record	66-73			59-73	59-73	68-73		69-70						62-73			62-73	
Powder River at Moorhead, Montana																		
No. of samples	67	33	34	34	55	1/	-	-	31	30	9	9	7	10	7	-	6	8
Maximum value	25.5	12.4	10.0	8.5	4600	4080	-	-	0.61	3.20	5.0	30.0	0.9	2200	11.0	-	448.0	32.0
Minimum value	0.0	5.2	0.6	7.4	8	676	-	-	0.00	0.0	0.0	0.0	0.0	0.0	0.0	-	241.0	0.0
Mean value	10.5	9.0	3.0	8.0	642	1552	-	-	0.09	0.54	1.0	10.4	0.2	500	3.7	-	274.8	16
Period of record	69-72	69-72	69-72	69-72	69-72	69-72	-	-	69-72	69-72	69-72	69-72	70-72	69-72	70-72	-	69-72	69-72
Yellowstone River at Sidney, Montana																		
No. of samples	97	18	18	311	375	37	24	23	25	41	4	4		83		4	79	4
Maximum value	24.4	12.6	3.3	8.9	65240	655	15500	.69	.26	2.7	0	10		800		200	260	0
Minimum value	0	7.4	.9	6.9	1149	230	167	0.0	0.0	.01	0	8		100		100	20	0
Mean value	11.3	9.8	1.8	7.8	14527	460	2308	.2	.06	.32	0	2.5		449		150	146.4	0
Period of record	65-73	70-73	70-73	59-73	59-73	68-73	65-72	69-70	69-72	69-73	66	66		59-73		66	54-72	66
Knife River at Golden Valley, N.D.																		
No. of samples	51			107	140	105	30	106	43	2		1		107			107	1
Maximum value	23.9			8.6	9620	2700	3340	9.3	9.3	.58		40		900			1200	20
Minimum value	0			6.6	.2	114	66	.2	.7	.05		40		100			50	20
Mean value	9.6			7.8	340	1004	1201	2.31	3.85	.32		40		486			257.5	20
Period of record	63-73			63-73	63-73	63-73	63-65	63-73	64-65	65-72		1965		63-73			63-73	1965
Heart River at Mandan, N.D.																		
No. of samples	63	63	63	63		60				26								
Maximum value	25	16.2	8.9	9.0		2280				.76								
Minimum value	0	3.7	.8	7.0		175				.01								
Mean value	10.3	9.6	2.9	8.0		844				.11								
Period of record	68-73	68-73	68-73	68-73		68-73				71-73								
Cannonball River at Breien, N.D.																		
No. of samples	25			26	26	26		6		16				26			25	
Maximum value	24			8.3	2770	1960		4.8		.21				1400			860	
Minimum value	0			7.2	15	285		1.0		0				100			0	
Mean value	10.2			7.8	414	1139		2.68		.02				546			346	
Period of record	70-72			70-72	70-72	70-72		70-72		71-72				70-72			70-72	
Missouri River at Bismarck, N.D.																		
No. of samples	797	400	346	653	581	360			288	24	16	16		11	2	13	18	16
Maximum value	22	14.3	6.0	8.6	36400	655			.9	.87	60	50		700	.1	59	360	42
Minimum value	0	6.1	0	7.7	1040	268			0	.01	4	10		450	.01	9	91	2
Mean value	8.3	10.6	1.1	8.3	18239	425			.34	.04	33.6	22		519	.2	37.3	217	20.4
Period of record	57-73	58-73	58-73	57-72	57-65	58-73			58-66	65-69	62-71	62-71		63-68	62-63	63-71	63-71	63-71
Belle Fourche at Wyoming-South Dakota border																		
No. of samples	55	12	12	193	182	121	2	69	8	8	7	7	6	182	8	2	188	6
Maximum value	28.3	12.7	4.2	8.6	917	2450	510	4.10	.75	.88	40	14.0	.5	1100	70	90	470	140
Minimum value	0.0	7.5	.8	6.6	3	428	218	0.0	0.0	.02	1.0	2.0	.2	70	0	57	0	10
Mean value	10.8	9.7	1.7	7.8	111	1190	364	.58	.14	.35	12.6	4.7	.3	770	13.9	73.5	158.6	56.7
Period of record	60-73	70-73	70-73	60-73	60-73	67-73	60	67-71	70-72	70-72	70-72	70-72	70-72	60-73	70-72	70-71	60-73	70-72
Cheyenne River near Wasta, South Dakota																		
No. of samples	23	10	10	16	22			10	10	10	4	4		4			4	4
Maximum value	27	14	20	9.5	1150	2060		1.8	.78	5.9	3	37		1400			274	28
Minimum value	0	6.2	.9	7.5	6	350		0	0	.07	0	0		400			123	0
Mean value	8.6	10.7	3.6	8.1	654	1066		7.8	.78	.35	.8	9.6		800			218	16.6
Period of record	69-70	69-70	69-70	69-70	69-70	55-57		69-70	69-70	69-70	69-70	69-70		69-70			69-70	69-70

watering, recreation, fish and wildlife, and municipal and industrial purposes. A summary of the water quality for the Northern Great Plains streams (one station per stream) is given in Table 2.

Wide variations in the mineral quality of water may be noted in individual streams throughout the program area. High quality water is found in the Yellowstone River. Dissolved solids in the Yellowstone near its mouth range from a low of 230 mg/l to a high of 655 mg/l with an average of 460 mg/l. In contrast, the Powder River contains poorer quality water. Dissolved solids in the Powder near Moorhead average 1552 mg/l with highs and lows of 4080 and 676 mg/l, respectively.

Suspended sediment concentrations and loads vary widely both throughout the region and throughout the year (at a given site). The sediment load is normally light in the upper reaches of the major streams but increases in the middle and lower reaches. Sediment concentrations have historically been detrimental to consumptive uses of water as well as to fisheries and recreation in some stream reaches. The average sediment loads at the mouths of the Yellowstone and Powder Rivers are 0.27 and 0.40 AF/sq. mi./year. More data are needed on suspended solids concentrations.

Biological quality of surface water characterized by nutrients, dissolved oxygen, and bacterial concentrations is considered good except for some localized problems. Some areas are considered to be deficient in nutrients to support aquatic life. On the other hand, some areas contain quantities of nutrients at such levels as to indicate the potential for problems from overgrowth of aquatic plants if further stimulation occurs. The dissolved oxygen level of streams ranges from excellent to satisfactory throughout most of the year. However, a marked reduction in oxygen levels may be found during the summer below some municipal and industrial wastewater outfalls and in some reaches with low flows resulting from diversions and natural conditions. Bacterial concentrations are generally low due to the low level of population and industrial activity in the Region. The effect of diversions and return flows on stream temperatures is more noticeable in summer months because of the increased demand at that time for domestic, irrigation, and industrial water.

Very little data are available describing the concentration of trace elements in the rivers of the Northern Great Plains. Collection of adequate background data is desirable and possibly essential, but information collected on trace elements has not shown serious problems to date.

Only sparce data are available to describe the radiological quality of streams. Concentrations of radioactivity in the samples that have been taken are below limits generally recognized as safe.

Data on the biological water quality in the region are scarce. While fishery information is generally available, data for plankton, benthos, and other aquatic organisms are particularly limited. The upper reaches of most of the streams, particularly those in Wyoming and Montana, have good to excellent cold water fisheries. As streams progress downward and onto the plains, water quality generally decreases and cold water fish species are replaced by warm water fish species.

Current Surface Water Use

Uses of water can generally be classified into the broad categories of consumptive use and non-consumptive use.

Consumptive Uses. — Those uses which diminish the quantity of surface water are called consumptive. Irrigation is by far the largest consumptive use in the region. Other major consumptive uses are evaporation from reservoirs and ponds, and watershed treatment. Municipal supply, rural domestic and livestock supply, fish and wildlife development, mining, and thermal powerplant cooling all use relatively minor amounts of water in the Region.

The average annual depletion (water consumed) in the Missouri River Basin above Sioux City, Iowa, was about 2.7 million acre-feet in 1910, most of which was for irrigation. By 1949 depletion had increased to 3.7 million acre-feet, and by 1970 to about 6.5 million acre-feet, but these depletions include evaporation from the main-stem reservoirs which were completed during these periods. Records of depletions by basin prior to 1910 are not adequate, but the following tabulation shows the increase in depletions from 1910 to 1970 for the major river basins in the study area:

River Basin	Increase in Average Annual Depletion, 1910-1970 (Acre-Feet)
Clarks Fork Yellowstone	4,300
Wind-Bighorn	372,000
Tongue	16,200
Powder	31,900
Total Yellowstone (including above)	629,900
Missouri above Garrison Reservoir	1,258,000
Little Missouri	28,700
Knife	5,200
Heart	23,800
Cannonball	9,400
Grand	51,500

Non-consumptive Uses.-- Uses which do not diminish the quantity of water are non-consumptive uses, such as hydroelectric power generation, navigation, fish and wildlife, recreation and esthetics. Some of these, such as hydropower and navigation, consume no water but sometimes require storage which does consume water through evaporation. Those uses which depend on existing natural streamflow are usually affected by variations in the flow. Many streams in the study area experience wide variation in flow over a period of years, with some reaching zero flow at times, as shown in the following tabulation:

River and Location	Recorded Minimum Flow (c.f.s.)	Recorded Maximum Flow (c.f.s.)	Computed Average Flow (c.f.s.)
Yellowstone at:			
Corwin Springs	389	32,000	3,110
Livingston	590	-	3,740
Billings	430	66,100	6,860
Miles City	996	96,300	11,330
Sidney	470	159,000	13,030
Clarks Fork Yellowstone at:			
Edgar	36	10,900	1,060
Wind-Bighorn at:			
Riverton	10	13,300	940
St. Xavier	228	37,400	3,550
Bighorn	275	-	3,850
Tongue River at:			
Decker	4	7,480	450
Miles City	0	13,300	420
Powder River at:			
Arvada	0	100,000	270
Locate	0	-	620
Little Missouri at Medora	0	65,000	480
Knife River at Hazen	0	35,300	180
Heart River at Mandan	0	30,500	260
Cannonball at Breien	0	94,800	250
Grand River at Little Eagle, S.D.	0	15,000	230

Most of the hydropower capacity which is in the study area or affected by it is at the six main-stem dams on the Missouri River: Fort Peck in Montana, Garrison in North Dakota, and Oahe, Big Bend, Fort Randall and Gavins Point in South Dakota, with a combined total capacity of 2,048 megawatts. Total hydropower capacity in the Yellowstone Basin is 296 megawatts of which 250 megawatts are at Yellowtail Dam on the Bighorn River.

There is no major commerical navigation in the Missouri Basin above Sioux City, Iowa, but downstream navigation depends in part upon water stored behind the Missouri main-stem dams above Sioux City.

The Yellowstone River proper and its major tributaries generally support cold water fish in their upper reaches and warm water species in the lower reaches. From time to time the minimum flow in some streams becomes zero or so near zero that fish are destroyed or forced to congregate in remaining pools where food supplies are limited, and spawning may be adversely affected. At higher elevations in the Yellowstone subbasin the flows are more stabilized and the water is generally of good quality and may be characterized as clear, well-aerated and relatively low in nutrients. Productivity increases downstream resulting in rapid fish growth and abundance of fishes. Where not degraded, this habitat supports rainbow trout, brook trout, brown trout, and cutthroat trout. Whitefish and nongame species coexist with trout in some areas. Warm water species largely replace trout at lower elevations with the more important species including the paddlefish, sauger, channel catfish, goldeye, small mouth buffalo, and rock bass.

The western Dakota tributaries are characteristically highly fluctuating systems with pools 8 to 12 feet deep. The pools are important habitats in which fish survive during periods of low flow. Species inhabiting these streams include catfish, northern pike, sauger, sunfish, perch, bullhead, darters, and dace. During the spring flow, these tributaries are important in maintaining the fish populations in Lake Sakakawea, Lake Oahe, the Missouri River, and the tailraces of Garrison and Heart Butte Dams.

From the standpoint of fish life some variation in flows is desirable and even essential. Freshets trigger movements of some species to upstream spawning area; high flows make passage past obstacles possible, clean gravel areas, and periodically remove vegetation which would otherwise encroach on the river channel.

Within the study area several chronic problems adversely affect the use of fishery resources or limit proper fishery management: (1) periods of low or zero flow in streams. (2) stream channel alterations: and (3) limited legal access to fishermen.

Water oriented and water-related recreation is an important part of total recreation. Some of the types in this category are sightseeing, camping, picnicking, swimming, hiking and walking, boating, and water skiing, and fishing and hunting. Demand is continually increasing for water-oriented recreation, both that related to flat water and that related to free-flowing streams. Interest is increasing in preserving some reaches of rivers with outstanding scenic and wilderness qualities.

In September 1970, the Secretary of the Interior announced the following additions to the 5d list for Wild and Scenic River consideration: (1) Missouri River from Fort Benton to Fort Peck, (2) Yellowstone River from Yellowstone Park boundary to Pompeys Pillar, (3) Little Missouri - segment from Marmarth, North Dakota, to Lake Sakakawea, (4) Green River above Daniel, and (5) Wind River above Boysen Reservoir. Some of the other rivers, or reaches thereof, may possess characteristics which could qualify them for future consideration and classification.

More information on wild-scenic-recreation values is contained in the Wild-Scenic-Recreation Appendix and in the report of the Wild-Scenic-Recreation Subgroup.

Several State and Federal agencies are developing methodology and guidelines for quantifying instream flows needed for environmental quality as well as fish and game purposes. Generally what is meant by instream uses or instream flows is the amount of water needed for fisheries, recreation, and aesthetic purposes. However, other purposes may be of equal or greater concern in certain stream reaches, (maintenance of the stream associated ecosystem, fur-bearer management, wilderness preservation, et cetera). With rapidly increasing demands for water, it is imperative the preliminary minimum instream water requirements needed to maintain physical, chemical, and biological conditions necessary to sustain aquatic communities (including fish populations) and riparian habitats be determined now. More definite and detailed answers may require several years of field investigation.

Existing and Pending Water Purchase Options

A look at current industrial activity shows a rapidly growing interest in both coal and water. Only 6 or 7 years ago, strip mining was active at only three to four locations primarily for local steam-electric generating needs and a minimum number of industries were investigating water availability. There is now a flourish of strip mining for export and planning is progressing on new generating stations. Water filings are being made and older irrigation water rights are being purchased for conversion to industrial uses.

Since 1967, option contracts to purchase storage water have been taken (or are pending) by more than a dozen companies. Additional applications have been received. Table 3 following shows the amounts of water for the options and applications through October 1974. No water under option has been put to use or diverted as of now.

Ground Water

Shallow Ground Water

Ground-water conditions in shallow aquifers were considered for three priority areas in the northern Great Plains--the Gascoyne area in North Dakota, the Gillette area in Wyoming, and several subareas within the Birney-Decker area in Montana. Shallow aquifers are defined as those aquifers overlying the Pierre Shale; they include alluvium, sandstone or coal beds in the Wasatch, Fort Union, Lance, and Hell Creek Formations, and the Fox Hills Sandstone.

The Gasocyne area is on the western edge of the Williston Basin. Ground-water movement is generally northeastward toward discharge areas along the Missouri River Valley. Permeability of the lignite beds is not known, but probably is comparable to the average permeability of the sandstone aquifers, which is about 2 feet per day. Major constituents in the water are calcium, magnesium, sodium, bicarbonate, and sulfate. Dissolved solids range from about 1,500 to 2,000 mg/l. Concentrations of calcium and magnesium generally decrease with increasing depth as sodium and bicarbonate become the dominant ions.

The Gillette area is near the eastern edge and the Birney-Decker area is in the north-central part of the Powder River Basin. Ground-water in the deepest of the shallow aquifers--Basal Hell Creek-Fox Hills in Montana or Lance-Fox Hills in Wyoming--flows generally northward and discharges by upward leakage along the Yellowstone River Valley and along the lower reaches of the Tongue River and Powder River Valleys. The direction of ground-water movement in the Fort Union and Wasatch Formations is controlled largely by the local topography. Water enters the system along the interstream divides and moves downward and laterally toward the nearby valleys. Much of the water is discharged by springs, seeps, or wells, but some enters the alluvium along the stream valleys where it augments streamflow or underflow and is eventually largely dissipated by evapotranspiration.

Table 3

Industrial Water Option Contracts and Applications as of October 1974

Water Source	Federal		State	
	Executed Or Pending Contracts (A.F./year)	Additional Applications (A.F./year)	Tentatively Approved Permits[1] (A.F./year)	Additional Applications (A.F./year)
Boysen Reservoir Wind River, Wyoming	85,000	9,000		
Yellowtail Reservoir Bighorn River, Montana	623,000	502,000		
Tongue River Reservoir Tongue River, Montana			4,000[2]	
Moorhead Reservoir (Potential) Powder River, Montana		220,000		
Fort Peck Reservoir Missouri River, Montana		732,000		67,000[4]
Beaver Creek (Potential Reservoir) Little Missouri tributary				36,000
Lake Sakakawea Missouri River, North Dakota		59,000	42,000[3]	234,000
Lake Oahe Missouri River, N. and S. Dakota		125,000		
Lake Tschida Heart River, North Dakota		18,000		
Shadehill Reservoir Grand River, South Dakota		19,000		
Yellowstone River and Tributaries Montana		630,000		913,000
Totals	708,000	2,314,000	46,000	1,250,000

[1] Does not include use by existing plants

[2] Executed contract with State of Montana

[3] State permits issued, but no Federal contracts yet executed

[4] Application for this same water is included in the 732,000 acre-feet listed under Federal

Major constituents in water from bedrock aquifers in both the Gillette and Birney-Decker areas are calcium, magnesium, sodium, bicarbonate, and sulfate. Dissolved solids average about 2,000 mg/l in the Gillette area and about 1,500 to 2,000 mg/l in the Birney-Decker area. As in the Gascoyne area, amounts of calcium and magnesium decrease with depth as the amount of sodium increases.

Detailed and specific information on the areas investigated is contained in the report by the Ground Water Subgroup entitled Shallow Ground Water in Selected Areas in the Fort Union Coal Region.

Deep Ground Water

Recent study has indicated that substantial amounts of water may be available from deep aquifers in some areas of the coal region. Near the Black Hills this ground water has less than 1,000 mg/l dissolved solids, but in much of the coal region TDS ranges between 1,000 and 2,000 mg/l. The water may be suitable for energy development, but is marginal to unsatisfactory for irrigation or other specialized uses demanding water of good quality.

Further information on deep ground water is contained in the Ground Water Subgroup report entitled Possible Development of Water from Madison Group and Associated Rocks in Powder River Basin, Montana-Wyoming.

CONSTRAINTS TO WATER RESOURCE DEVELOPMENT

General Discussion of Constraints

This discussion of constraints to water resource development is limited to constraints regarding quality, quantity, storage, diversion, and conveyance of water for development of coal resources in the Northern Great Plains Area. Constraints on coal development regarding socio-economic and cultural aspects, surface resources, atmospheric aspects, mineral resources, regional geology, and national energy considerations are being considered in depth by other work groups of the Northern Great Plains Resource Program. The principal constraints related to water development and use can be classified as legal, institutional, social, cultural, aesthetic, economic (physical), technical, environmental, and ecological.

Development of water resource projects and utilization of available water supplies for competing uses is a complex subject. Throughout the years, development of water resources of the Northern Great Plains States has been carried out by a combination of the Federal Government, States, political subdivisions, private groups, and individuals. Many of the earlier water resource projects in the Northern Great Plains Area were constructed and financed primarily by individuals, private groups, and political subdivisions, but increasing complexity and higher costs of water resource development soon began to exceed the financial resources and legal powers of those interests.

The increasing complexity of water resource projects over the years has led to progressive enactment of a body of Federal legislation which has permitted greater utilization of technical and financial resources of the Federal Government to plan, construct, and where appropriate, to operate water resource developments in coopeartion with the States and their political subdivisions. In addition, many laws regarding water resource development have been enacted in the individual States, and compacts regarding interstate waters have been agreed to by some of the States.

Federal and State laws relating to the use of water are, in some cases complementary and, in other cases, conflicting. Many of the conflicts can be resolved by use of the McCarran Amendment (66 Stat. 560; 43 U.S.C. S666) which permits a general water right adjudication in a State court in which the United States may be named a party.

Even though many of the laws are basically authorities for various actions by the Federal and State Governments, they also establish the constraints to be followed in the planning, construction, and operation of water resource projects. Further constraints are placed by the institutions responsible for implementing the laws, such as Federal agencies, State health departments, regional water commissions, State water resource departments, and other local, State, and Federal agencies. Institutional constraints arise as a result of the laws and from the licenses, permits, approvals, et cetera, needed to satisfy the agencies that the laws, rules, and regulations are being obeyed.

The major legal constraints include State water laws, policies, and administration; interstate compacts; the Constitution, laws and treaties of the United States; and Federal statutory provisions. There are laws delineating authorities and constraints on the various aspects of multipurpose water resource development such as those relating to Indian land and waters, irrigation, power, navigation, municipal and industrial water, flood control, watershed protection, recreation, fish, and wildlife. Recent legislation such as the Federal Water Pollution Control Act Amendments of 1972 and the National Environmental Policy Act of 1969 have greatly broadened the scope of items to be considered in planning, construction, and operation of water resource projects.

Social, cultural, and aesthetic constraints are not easily identified. There may be no easily quantifiable constraints that dictate no development in a certain area, yet strong reasons may exist for leaving certain areas undisturbed. In the Northern Great Plains Area there exist certain rivers that are still free-flowing, scenic, and recreational streams such as the Upper Yellowstone. These type streams are relatively rare today. Therefore, although no specific legal constraints may exist, social or aesthetic constraints should probably be exerted within responsible institutions. Some resistance to any development exists in the Northern Great Plains Area today. How much of this resistance is merely a normal attitudinal resistance to change, per se, and how much resistance represents a valid social or cultural constraint can only be speculated. However, it must be kept in mind that social constraints frequently manifest themselves in legal road blocks.

Economic and physical aspects can also be a constraint. To provide a dependable water supply from a river, storage must be provided in many cases to make the supply of water available in all years. The cost of storage and regulation plus the cost of conveyance facilities to the point of use can be so high because of physical conditions that the water used would not be delivered at a cost the water user would be willing to pay. Also the method of repayment and repayment period could be a constraint.

Although many times they are not recognized as such, technical constraints are also important. The available technology for pollution abatement may not be advanced sufficiently to allow standards to be met. For example, liquid effluents from certain energy conversion facilities may not be amenable to conventional waste treatment. Further, when considering the development of a nonrenewable resource, there may be a lack of sufficient technology for satisfactory energy conversion.

Moreover, environmental or ecological constraints not adequately addressed within the normal concept of constraints may be critical. In the Northern Great Plains Area, there are a number of ecosystems which are delicately balanced, complex, and sensitive to alteration and modification. Lack of knowledge of these systems, their function and relationship between one another, and the amount of change a system can tolerate without unacceptable or irrepairable damage, should be viewed as a critical constraint. Because the data base is not adequate in all places, application of such a constraint may be difficult. The identification of an instream minimum water flow for each stream in the Northern Great Plains Area is an example of the recognition of such a constraint, and the problems in developing an acceptable methodology for establishing instream flow shows lack of adequate knowledge in this area.

It is recognized that social, cultural, aesthetic, economic, technical, environmental, and ecological aspects are constraints to water resource development in addition to legal and institutional constraints. However, it must be recognized that it is law that establishes the basic authority to consider the other constraints in the planning process. Various Federal and State agencies administer the laws to assure that the constraints are properly evaluated in any project prior to approval for private construction or consideration for authorization for construction by the Congress. The following paragraphs outline those principal legal and institutional constraints regarding water resource development in the Fort Union coal region of the Northern Great Plains Area.

State Water Laws, Policies, and Administration

Recognizing the many variations among the five States in the Northern Great Plains Area, and the complexities within each, obviously it is difficult to accurately summarize their laws, policies, and administration in the field of water resources. Specific water right problems and in-depth water policy issues must be explored with legal counsel or by contact with State officials thoroughly conversant with water laws and their many ramifications.

In the general field of water laws, two fundamental doctrines were adopted in the five States—the riparian rights doctrine and appropriation rights doctrine. Montana and Wyoming have specifically repudiated the riparian doctrine and have established the appropriation rights doctrine. Nebraska, North Dakota, and South Dakota depend on the appropriation rights doctrine, but recognize the riparian doctrine in varying degrees in relation to the statutory rights. In these three States, a riparian landowner could claim a water right to the extent of his reasonable use, but all waters in excess thereof remained subject to appropriation. However, North Dakota and South Dakota passed legislation in 1955 which provided that thereafter riparian landowners were to be governed by the same laws and would be obliged to follow the same appropriation procedures as nonriparian landowners. This legislation did not apply to landowners who were exercising or developing their riparian water rights at the time legislation was enacted.

Riparian Rights Doctrine

The common-law doctrine of riparian rights is based primarily on the ownership of lands and uses of water thereon contiguous to the stream. Such law emanates from the judiciary in resolving actual disputes, and the rights and obligations pertaining to water and its uses thus have their origin in a substantial body of court decision.

Under the riparian rights doctrine the owner of land contiguous to a natural stream or natural lake may use the waters for such purposes and in such quantities as he chooses, as long as he does not appreciably diminish the flow or impair the quality of water for downstream uses. The riparian owner's right is the same as all other riparians on that stream, and it is not acquired by actual use nor lost by failure to use the water. Such rights are not expressed in specific quantities of water unless they have been apportioned by the court. Where streamflow is ample, this permits full beneficial use by the riparian owners, but otherwise the available water must be divided on some equitable basis. Thus there is no priority of right, although upstream domestic use and the watering of domestic livestock generally are considered preferential uses. However, commercial livestock watering and irrigation generally do not enjoy this preference. With the riparian rights available only to lands contiguous to the stream there usually is no basis for the transfer of rights to lands not contiguous, including those of another basin.

Appropriation Rights Doctrine

Under the appropriation rights doctrine the beneficial use of water is the basis, the measure, and the limit of the water right. The first beneficial appropriation in time is prior in right. Appropriations are for a definite rate of direct-flow diversion or storage, and often the total quantity is specified as not to exceed a given acre-feet total per acre per season, or simply in total acre-feet, as for storage.

An appropriation right is perfected and sustained only by actual and continuous beneficial use. Generally, failure to make beneficial use of a perfected appropriation for a specified period (3 to 10 years) can result in its abandonment, forfeiture, cancellation, or reduction, generally following notice by the State and a hearing. Appropriated water may be used for beneficial purposes either on lands contiguous to or at a distance from the stream. In many basin States water can be taken into adjacent watersheds or basins.

Under the exclusive system of appropriative rights, all water in the natural stream is subject to appropriation. However, in most cases there is separate consideration and accounting for water taken under direct flow, as against storage rights. Generally, the appropriator is entitled to collect seepage and return waters, by means of drains or ditches, upon any part of the lands under a project or canal for reapplication to those lands. Generally such return waters, upon reaching the stream, may be appropriated and put to use by others. The Montana Water Use Act permits a reservation of flows for future use or to maintain minimum flows. Other States do not have this provision.

A generally recognized rule is that an upstream junior right is not required to close his diversion gates to pass water to a downstream senior right when the stream conditions are such that there is no reasonable likelihood that usable quantities of water would reach the senior diversion. The principle that there may be no waste of water is unquestioned.

Water may be stored, either in channel or off-channel reservoirs, for future beneficial use under reservoir decrees in order of priority. Normally a junior direct-flow right is precluded from taking water ahead of a senior storage right. Junior diversions for storage cannot take place when such water is needed by direct-flow appropriators or for reservoirs having senior storage rights. Generally the rights of a reservoir owner are limited to an annual quantity of water equal to one filling, unless there is "free water" in the stream not demanded by other appropriators. In most appropriation States the exchange of stored water for direct-flow water is permitted if other users are not adversely affected. By statute, reservoir owners are generally liable for loss or damage caused by failure of the dam or reservoir.

Reservoir releases, and also transbasin imports in Wyoming, intended for downstream use are administered by the State for delivery and use only by the appropriator, with appropriate deductions in quantity for stream losses. Waste water, seepage, and releases from flood control and hydroelectric storage reservoirs, discharged with no intent to recapture, may be appropriated, but where the appropriator cannot insist on continuance of such flow from the reservoir. A water user in one State cannot contravene any right to the use of water allotted by interstate compact or court decree to another State.

Water Administration

In the five States of the Northern Great Plains Area, there is a basic pattern that is similar, but still showing quite a variation in the policies and administration of water and related land resources. Here it is possible only to draw attention to the pattern of State agencies with duties and powers in the fields of water studies, water and related land resource planning, water development and control, and water administration.

Water and Related Land Resources.--Historically water resource development has been accomplished by individuals, mutual companies, cities and towns, or through local districts created in accordance with enabling legislation. Special-purpose districts have been authorized by the States, often with limited objectives, but with a recent trend towards the broadening of authority accompanying greater emphasis on multipurpose developments and services affecting larger areas. Each of the States has authorized conservancy-type districts with broad authorities generally encompassing large water-service areas. South Dakota has enacted legislation establishing a statewide conservancy district, with authority for local people to create sub-districts through local petition, public hearing, voting, and public certification. Montana at one time authorized its Water Resources Board, now absorbed into the Department of National Resources and Conservation, to engage in the construction of water development projects. The Board marketed water through water user associations whose income from sales was applied as repayment of project costs, including operation and maintenance. North Dakota also has a State-funded development program in this respect. Several of the States have authorized their water resources boards to purchase reservoir storage capacity under the Federal Water Supply Act of 1958 and, in turn, to dispose of the water for municipal and industrial uses. Most often the State obligation for repayment is based on specific authorization of the legislature for each project. Wyoming currently makes loan money available to water development associations.

Water Right Administration.--Although a user may obtain a water right by appropriation under statutory procedure, the water right is a use right which must be exercised in the manner and by the method specified in the State permit. Thus there is the necessity for water right administration by the State.

Each of the five States has provided an agency to administer surface water rights. The State agency is directly responsible for receiving and processing the applications or filings. Further, it polices the streams and diversion works as necessary to guard against violation of water rights that have been granted and put into active use. It also accounts for, makes suitable deductions for stream channel losses, and thus assures delivery of reservoir or imported waters to the appropriator. Generally the statutes provide separately for administration of the direct use of natural flow and of stored or imported water, and increasingly for some administration in the development and use of ground water separate from or in conjunction with surface waters. Although the methods of acquisition of these appropriations are basically the same, each type has limitations peculiar to the authorized uses. All active rights are limited to the amounts that can be used beneficially within the terms of the permit. For irrigation some States limit the rate of surface water diversion per acre, and others such as Nebraska also limit the annual use per acre from direct flow or storage. Most of the appropriation laws have some provisions for a change in place of use, but the requirements vary among the States. Montana adopted a new water use act effective July 1, 1973, which created the need for a declaration of water rights by the ostensible owner, followed by a determination of the character of the rights through State administrative or judicial action.

When the natural water supplies are insufficient for all needs, there may be a change in water use to a higher preference, but this is not to be confused with priorities. Most of the States under the priority system permit interference with or condemnation of a senior right by a junior right for a superior or preferential purpose (normally for public use) but only upon payment of just compensation to the prior appropriator. Domestic use has the highest preference, followed generally by use for irrigation, and manufacturing or other industrial purposes.

Interstate Compacts

Where rivers cross State boundaries, and with mounting usage, there can be problems in allocation of the interstate water and administration of water rights. Because of these problems and existing or impending litigation, several affected States have entered into interstate compacts or requested court apportionment of the affected waters for the river systems.

The Federal Constitution provides that no State shall enter into any agreement or compact with another State, or with a foreign power, without the consent of Congress. Approval by Congress is required once the compact is ratified by the several States and usually provides for a Federal representative serving and reporting on the negotiations. The interstate compacts which are applicable to the Fort Union region are the Belle Fourche River Compact and Yellowstone River Compact.

The Belle Fourche River Compact between Wyoming and South Dakota was approved by the Act of February 26, 1944. Under this compact water right priorities theretofore established in one State were to be recognized in the other. Of the remaining unappropriated water, 90 percent is to be allocated to South Dakota and 10 percent to Wyoming. Diversions and impoundments of water in one State for use in the other State are authorized where State appropriation laws are observed.

The Yellowstone River Compact among Wyoming, Montana, and North Dakota was approved by the Act of October 30, 1951. It divides Yellowstone River Basin Surplus waters (1) in the Clarks Fork, 60 percent to Wyoming and 40 percent to Montana; (2) in the Big Horn River, 80 percent to Wyoming and 20 percent to Montana; (3) in the Tongue River, 40 percent to Wyoming and 60 percent to Montana; and (4) in the Powder River, 42 percent to Wyoming and 58 percent to Montana. The Compact provides that the three signature States will not singly or jointly take actions which adversely affect Indian water rights to those waters of the Yellowstone River or its tributaries. Diversions and impoundments in one State for use in another State are authorized where State appropriation laws are observed. Diversions out of the Yellowstone Basin require the unanimous consent of all of the compacting States.

Federal Constitutional Provisions

The Constitution, laws, and treaties of the United States provide a spectrum of authorities relating to water resource development. However, the powers of the Federal Government are limited to those expressly delegated or reasonably implied from the Constitution.

Commerce Clause

The Commerce Clause vests in the Federal Congress the preeminent right to control navigable waters in the interest of commerce. This clause provides that the Congress "shall have power to regulate commerce with foreign nations and among the several States and with the Indian tribes," and is cited frequently as the authority for the Federal Government to engage in water resource development. Commerce control of water includes

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not only control for navigation, but also for flood protection, watershed development, and recovery of the cost of improvements through the production and sale of water-generated electric power. When the flow of nonnavigable streams is required to maintain the capacity of a navigable stream, the obstruction or limitation of such flows may be prevented by Federal action.

Waterways judicially held to be navigable in the general Northern Great Plains Area include Missouri River from Three Forks, Montana, to Fort Benton, Montana, and Bighorn River in Montana and Wyoming. Also, the Missouri River below Fort Benton, Montana, has been administratively held to be navigable so as to be subject to Coast Guard regulations.

Property Clause

The Property Clause provides that "The Congress shall have power to dispose of and make all needful rules and regulations respecting the territory or other property belonging to the United States." This grant of power permits the United States to reserve water, for present and future use, in nonnavigable and navigable waterways which cross or abut land areas reserved for Federal purposes. The quantities of water which can be so reserved are those required to carry out the purpose for which the Federal lands were reserved. The Property Clause also has been used to affirm Federal authority to build irrigation projects serving Federal lands.

General Welfare Clause

The General Welfare Clause authorizes the Congress to use Federal revenues to provide for the general welfare of the United States. This grant of power permits the Congress "to promote the general welfare through large-scale projects for reclamation, irrigation, or other internal improvements."

Treaty Clause

The Treaty Clause authorizes the President to make treaties with the advise and consent of the Senate. Such power is unlimited except by those restraints found in the Constitution itself, and those arising from the nature of the State and Federal Governments. A treaty could not authorize what the Constitution forbids, nor could it change the character of Federal or State Government, nor could it impose a cession of State territory without consent of the State.

Treaties creating Indian reservations in the Missouri Basin have been held to imply that water was reserved for development of the reservation lands at least to the extent of irrigation potential.

Supreme Court

Under its constitutional powers, the Supreme Court of the United States may adjudicate water rights as between States. In such cases the doctrine of equitable apportionment may be applied. This doctrine means that the State which has first used the available interestate water may be allowed a continuing priority on its use.

Federal Statutory Provisions

From the standpoint of water and related land resource development, there are many Federal laws that bear heavily on resource development. These include several major laws and many lesser acts, in addition to the specific project authorizations. It is within the complementary pattern of these laws and those of the affected States, and through cooperative action in their application, that Federally assisted water and related land resource development has proceeded. In the following discussions each major function is discussed in the general order of date when it was firmly established as a national program in Congressional Acts, and began to have a major impact.

Indian Lands and Waters

Under several treaties, acts, and executive orders from 1868 to 1916, 23 Indian reservations were established in the Missouri River Basin. Responsibility for the administration of Indian lands and waters on these reservations rests with the Bureau of Indian Affairs; however, the rights to the lands and water actually are vested with the Indians or tribes. The Indians of each reservation appear to have some legal claim to the use of the waters located on or flowing through or along its boundaries. Such rights are read from the treaties and agreements between the Indian tribes and the United States which have been approved by acts of Congress or formalized by Executive Orders. The Indian people claim a right to these waters free from State regulation and with a priority at least as early as the date the reservation was recognized or established. The Indian water right priority is not conditioned on use and may be exercised at any time. The Indian right can be quantified by fixing the amounts of water needed to serve the purpose or purposes for which the reservation was established. (See Winters v. United States, 207 U.S. 564 (1908); Conrad Investment Co. v. U.S. 161 Fed 829 (9th cir. 1908); U.S. v. Walker River Irrigation District 104 Fed 334 (9th cir. 1939); U.S. v. Ahtanum Irrigation District 235 Fed 321 (9th cir. 1956); and in closing, Arizona v. California 373;546-600 (1963). Thus if the purpose were to promote an agricultural economy, as has been the case generally, the quantity of water reserved would be the amount needed to serve the practically irrigable acreage on the reservation. It also has been urged on behalf of the Indians that since the purpose of the Indian reservation is to provide an economic base for the Indian people residing thereon, it must follow that the Indian water right is a right to use the available reservation waters for any beneficial use including irrigation, livestock, domestic, power, recreation, industrial and municipal purposes. Nevertheless, several State water administrators continue to urge that the Indians are entitled only to that water for which proper application under State procedures has been made.

The irrigation of Indian lands was authorized by the General Allotment Act of February 8, 1887, which also provided that the Secretary of the Interior should make a just and equal distribution of the available water among the Indians. Later the Act of April 4, 1910, made specific provision for irrigation developments on Indian reservations, and special authorizations have been provided by Congress for many individual projects. The right to use Indian water for nonirrigation purposes has not been litigated or judically determined.

Irrigation

The Reclamation Act of 1902 signified the beginning of activities involved principally with providing for the irrigation of public and private lands in the 17 Western States by the Secretary of the Interior through the Bureau of Reclamation. Significant changes, including recognition of the multipurpose principles of water development, were made in the Reclamation Project Act of 1939 as an amendment to the 1902 Act. Authorized functions now include the planning and construction of works for impounding and diverting water for irrigation, power generation, municipal and industrial uses, recreation, fish and wildlife enhancement, stream regulation and pollution control, and (where approved by the Corps of Engineers) for navigation and flood control.

The Warren Act of February 21, 1911, permits the Secretary of the Interior to sell project water to nonproject water users and permit such users to carry or store water in project works if there is capacity surplus to the needs of the Reclamation Project. Several such contracts are operative in the Missouri Basin.

An important provision of the Reclamation Laws in term of Federal-State relationships is Section 8 of the 1902 basic Act which provides:

> "That nothing in this Act shall be construed as affecting or intended to affect or to in any way interfere with the laws of any State or Territory relating to the control, appropriation, use, or distribution of water used in irrigation, or any vested right acquired thereunder, and the Secretary of the Interior, in carrying out the

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> provisions of this Act, shall proceed in conformity with such laws, and nothing herein shall in any way affect any right of any State or of the Federal Government of any landowner, appropriator, or user of water in, to or from any interstate stream or the waters thereof· Provided, That the right to the use of water acquired under the provisions of this Act shall be appurtenant to the land irrigated and beneficial use shall be the basis, the measure, and the limit of the right."

Power

Section 5 of the Act of April 16, 1906, authorized the Secretary of the Interior to develop and sell electric energy in connection with Reclamation projects. Surplus power or power privileges can be sold or leased for periods not exceeding 40 years, with preference going to municipalities or other public corporations or agencies, and to cooperative and other nonprofit organizations having REA financing.

Basic authority of the Federal Power Commission for its water resources activities is the Federal Power Act, as amended. This Act relates to the licensing of non-Federal hydroelectric projects, and vests the Commission with jurisdiction (a) over the transmission and sale at wholesale of electric energy transported in interstate commerce and (b) over the public utilities involved.

Navigation

The Act of 1811 provided that all navigable rivers and waters of the Louisiana Purchase "shall be and forever remain public highways." Beginning with the Act of May 24, 1824, investigations and improvements for navigation and related purposes have been authorized by a series of rivers and harbors acts, from which basic policies and procedures have been established. The 1920 and 1960 Rivers and Harbors Acts clarified and expanded the Federal policy regarding navigation improvements, including small projects, and established requirements for cooperation where the benefits are mainly local in nature.

In the Flood Control Act of 1944, Congress made an important declaration of policy concerning works of improvements for navigation. The Act provides that "The use for navigation . . . of waters arising in States lying wholly or partly west of the Ninety-eighth Meridian shall only be such use as does not conflict with any beneficial consumptive use, present or future, in States lying wholly or partly west of the Ninety-eighth Meridian, of such waters for domestic, municipal, stock water, irrigation, mining, or industrial purposes."

Section 10 of the 1899 Rivers and Harbors Act provides, in the absence of Congressional authorization, that it is unlawful for anyone to undertake any work which results in an obstruction to the navigable capacity of any waters of the United States The Section also provides that it is unlawful to place any structure in any navigable waters of the United States without first securing a permit authorized by the Secretary of the Army Further the Rivers and Harbors Act allows the enjoining of discharges of a single slug (spill type not under an NPDES permit or not under Section 311 of Public Law 92-500) of solid waste, and of seepage or nonpoint source discharges traceable to a single source

Municipal and Industrial Water Supply

The Bureau of Reclamation first was authorized by Acts of April 16, 1906, and February 25, 1920, to provide and contract water for municipal and miscellaneous purposes. These authorities were restated in the Reclamation Project Act of 1939 for contracts up to 40 years. Similarly the Corps of Engineers can include storage space in reservoirs for domestic and industrial purposes under a law passed in 1944, later repealed, and reenacted in 1952. This authorized the Secretary of the Army to enter into contracts making surplus water available from reservoir projects at prices and on terms he deemed reasonable, but not as to affect then-existing lawful uses of the water.

Broader authority was granted to the Secretary of the Interior and Secretary of the Army in the Water Supply Act of 1958 to include storage space in Federal projects for both present and anticipated future municipal and industrial water supply. Prior to the initiation of construction or modification of a project to include water supply, State or local interests must agree to pay for the cost of the additional storage, or give reasonable assurance in the case of storage space included for anticipated future needs that they will contract for use of the storage Fifty-year repayment contracts at a suitable interest rate are authorized In the case of storage space included to provide anticipated future water supply needs, no repayment is required until the water supply is first used; further, no interest is charged from the date construction is completed to date of use, not to exceed 10 years. Not more than 30 percent of the total estimated construction cost may be allocated to storage space provided for future needs without prior Congressional approval The Secretary of Agriculture has similar authorities and requirements, as covered under "Watershed Protection and Flood Prevention."

Flood Control

Furthering earlier general legislation, the Flood Control Act of 1936 vested the Corps of Engineers with full responsibility for prosecuting flood control studies and improvements, This act stated that ". . . flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political subdivisions, and localities thereof." Subsequent flood control acts, and particularly that of 1944, expanded, modified, and amended the 1936 Act with respect to Federal involvement in all functional phases of water resource development, navigation, flood control, fish and wildlife, recreation, municipal and industrial water, and other uses The 1944 Act contained a policy declaration for coordination with State activities by recognizing the interests and rights of the States in determining the development of the watersheds within their borders, and rights in water utilization and control to preserve and protect, to the fullest possible extent, established and potential uses for all purposes.

Under provisions of the 1960 Flood Control Act, as amended, and directed by Executive Order of August 10, 1966, the Corps of Engineers furnishes flood hazard information and advice for use in planning to ameliorate the flood hazard, to local governmental entities and to Federal agencies. Flood plain information reports are prepared upon request of the State and local governmental agencies to delineate flood problems.

Watershed Protection and Flood Prevention

The Organic Administration Act of June 4, 1897, as amended, provides that the National Forests are established for securing favorable conditions for water flows, and to furnish a continuous supply of timber. The Act stipulates that all waters within the National Forest may be used for domestic, mining, milling, or irrigation purposes, under State laws, or under the laws of the United States.

The Act of April 27, 1935, directed the Secretary of Agriculture to establish the Soil Conservation Service to demonstrate, carry out, and cooperate in measures to conserve soil and moisture. In addition, the Flood Control Acts of 1936 and 1944 authorized him to make preliminary examinations and surveys for runoff and water-flow retardation and soil erosion prevention in watersheds, including emergency work.

The Watershed Protection and Flood Prevention Act of August 4, 1954 authorizes the Secretary of Agriculture to plan for and assist in financing projects for the control and use of water in watersheds not exceeding 250,000 acres in area. Project purposes may include flood prevention measures, drainage, irrigation, water supply, stream-flow regulation, fish and wildlife, recreation facilities, and municipal and industrial water supplies including storage of water for future municipal and industrial uses.

Outdoor Recreation, Fish and Wildlife

Under the Act of May 28, 1963, the Secretary of the Interior was authorized to conduct a comprehensive recreation resource inventory: prepare a system for classification of outdoor recreation resources: formulate and maintain a comprehensive nationwide outdoor recreation plan; provide technical assistance with respect to outdoor recreation: encourage interstate and regional cooperation: sponsor, engage in, and assist in research relating to outdoor recreation; and coordinate and promote interdepartmental cooperation. These responsibilities have been delegated to the Bureau of Outdoor Recreation. The Land and Water Conservation Fund Act of September 3, 1964, is widely regarded as one of the most far-reaching conservation-recreation measures enacted by the Congress. It provides financial assistance to States for planning, acquisition, and development of outdoor recreation resources. It also provides for Federal acquisition of recreation lands. The Federal Water Project Recreation Act of July 9, 1965 (P. L. 89-72) provides for the establishment of uniform policies with respect to giving full consideration ot the opportunity for recreation and fish and wildlife enhancement in Federal multipurpose water resource planning.

Similarly, the Fish and Wildlife Coordination Act of 1934 and several amendments provided basic authority for studies, modification of existing water projects, and to improve and develop fish and wildlife. As for recreation, the Water Project Recreation Act provided for States and other non-Federal interests to share specific development costs, and to assume operation and maintenance costs. The Bureau of Sport Fisheries and Wildlife and the National Marine Fisheries Service assist the States in development of projects for the restoration and management of fish and wildlife resources. Assistance to the States is available under the Federal Aid in Wildlife Restoration and Fish Restoration Acts of September 2, 1937, and August 9, 1950, respectively. The Endangered Species Preservation Act of 1966 vests the Bureau of Sport Fisheries and Wildlife with responsibilities for the National Wildlife Refuge System, and the Migratory Bird Treaty Act and Migratory Bird Conservation Act provide authority for enforcement and for refuge acquisitions requiring water supply.

The Multiple Use-Sustained Yield Act of June 12, 1960, makes it the policy of the Congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes. The purposes of this Act are declared to be supplemental to the Act of June 4, 1897, and direct the Secretary of Agriculture to develop and administer the renewable surface resources of the National Forest for multiple use and sustained yield of the several products and services obtained therefrom. Multiple use and sustained yield are defined in the Act.

The National Park Service was established by the Act of August 25, 1916, to administer all national parks, monuments, historic sites, and recreation areas. Its fundamental purpose is to conserve the scenary, natural and historic objects, and the wildlife, and to provide for their enjoyment by the people and yet leave the environment unimpaired for the enjoyment of future generations. Where public lands are reserved for these areas, sufficient water is reserved to carry out their purpose.

The Wild and Scenic Rivers Act became effective on October 2, 1968. In this Act, the Congress declared that ". . . the established national policy of dam and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes." The Act established the National Wild and Scenic Rivers System, designated eight rivers as the initial components of that system, and prescribed methods and criteria by which additional components could be added to the system from time to time. None of those rivers designated initially is located within the Northern Great Plains Area, but the segment of the Missouri River from Fort Benton to Ryan Island in Montana is listed as a potential addition to the system. Also, several rivers have been identified by the Secretaries of the Interior and Agriculture under Section 5(d) of the Wild and Scenic Rivers Act. This section provides that the free-flowing potential of these rivers must be evaluated and included as a specific part of any Federal planning report as a potential alternative use of the water and related land resources. The following rivers in the Northern Great Plains area have been so identified: Yellowstone River, Montana--segment from Yellowstone National Park boundary to Pompey's Pillar; Madison River, Montana--segment from Quake Lake to Ennis Lake; Little Missouri River, North Dakota--segment from Marmarth, North Dakota to Lake Sakakawea; Niobrara River, Nebraska--segment from Antelope Creek to vicinity of Sparks; and Wind River, Wyoming--segment from source to Boysen Reservoir.

Environment

On January 1, 1970, the President signed the National Environmental Policy Act of 1969 (NEPA) which establishes a national policy on the environment. The Act (1) states that the Federal responsibility is in cooperation with State and local governments to use all practical means to insure a healthful environment; (2) directs all Federal agencies, to the fullest extent possible, to administer programs in accordance with the Act and to consider the environmental impact of decisions; (3) requires the President to submit annually, beginning July 1, 1970, an Environmental Quality Report appraising status and progress; and (4) establishes a Council on Environmental Quality in the Executive Office of the President, to assist with the annual report, establish a system to monitor status of the environment, and review Federal programs affecting quality of the environment.

Implementation of NEPA required changes in the planning process to fully consider environmental values. These changes include the use of a systematic, interdisciplinary approach, use of ecological information, approropriate consideration of unquantified environmental values, and preparation of environmental impact statements. The court decisions on the environmental impact statement requirement of NEPA make it clear that Federal agencies must fully disclose potential environmental effects, consider all reasonable alternatives and carefully balance economic, technical, social and environmental factors in reaching a decision. While Federal agencies have taken many steps to revise their planning processes in response to NEPA, further changes will probably be required as NEPA is interpreted administratively and judicially. In the short term, NEPA will act as an administrative constraint until agencies have adjusted to its requirements. In both the short and long term, NEPA will act as a constraint as Federal actions must be modified in response to public review and comments on potential environmental impacts.

Water Quality

The "Federal Water Pollution Control Act Amendments of 1972" were enacted as Public Law 92-500 on October 18, 1972. The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Any new development in any area of the United States must be reviewed in light of the effect on water quality. The Federal Water Pollution Control Act Amendments of 1972 (FWPCA) clearly state that water pollution will no longer be tolerated. The following goals and policies were also clearly stated in the Act.

1. "It is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985.

2. "It is the National goal that wherever attainable an interim goal of water quality which provides for the protection and propagation of

fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983.

3. "It is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited."

Use of water in the development of natural resources in the Northern Great Plains Area must conform to the above objectives, goals, and policies. In addition to the broad overview provided above, specific tools were developed for both enhancing and protecting waters of the United States. Point source discharges, nonpoint source discharges, ambient water quality, diversions, intake structures, and even injection into the ground water are addressed in the FWPCA.

All discharges into "navigable waters"[1] (also including ground water) of the United States require a permit from Environmental Protection Agency (EPA) and/or the State which clearly regulates the quantity and quality of the discharge. A discharge is almost _any_ point source return flow of water, including cooling water and other industrial effluents, municipal discharges, irrigation return flow, and water pumped from mine pits. The effluent limitations in these permits are to be consistent nationally depending on the kind of facility (powerplant, steel plant, etc.) and reflect the application of the best practicable treatment technology (by 1977), the best available treatment technology (by 1983), or even more advanced pollution abatement technologies as needed to insure adequate receiving water quality. Clearly any water used by any development that is to be returned to any stream must meet certain levels of water quality. If technology does not exist to provide this level of treatment presumably there could be no development. (This would be tempered somewhat by Section 302 of the Act which provides for an exception under certain circumstances.)

The development of effluent standards representing the definition of best practicable treatment technology and best available treatment technology is presently underway for certain types of facilities, such as powerplants, and should be available soon. Standards for other types of facilities, such as coal gasification plants, have not been developed and currently are not under development. Further, standards of performance for new sources are also being developed. All new facilities will have to, at a minimum, apply the best available demonstrated pollution control technology, process, operating methods, or other alternatives to minimize pollution (including no discharge if such is appropriate).

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[1] The term "navigable waters" here includes:
1. All navigable waters of the United States
2. Tributaries of navigable waters of the United States
3. Interstate waters
4. Intrastate lakes, rivers and streams which are utilized by interstate travelers for recreation and other purposes
5. Intrastate lakes, rivers, and streams from which fish or shellfish are taken and sold in interstate commerce
6. Intrastate lakes, rivers and streams which are utilized for industrial purposes by industries in interstate commerce

Further, before a discharge will be allowed and a permit granted the State in which the discharge is to occur must approve of the discharge and certify that all provisions of the FWPCA will be met. Eventually all permits will be issued by the States and separate certification will not be necessary, but the same tight effluent requirements will be applied. The permits can be issued for up to 5 years at a time. Reapplication is necessary upon expiration and a reexamination of the adequacy of the effluent limits must be conducted.

In addition to controlling all discharges into waters of the United States, the FWPCA requires that all streams have definite minimum acceptable quality levels established. Section 303 of the FWPCA outlines a system whereby each State is required to develop water quality standards for both interstate and intrastate waters of the State. Such standards shall consist of the designated uses of the navigable waters involved and the water quality criteria for these waters based upon allowable uses. These standards must be compatible with Federal criteria on water quality and must be approved by the Administrator of EPA.

In order to provide guidance to the States in development of these water quality standards, and to assure that Federal minimums are addressed, Section 304 requires that EPA develop and publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare, the concentration and disposal of pollutants, and other information. This document was published in the Federal Register for comment on October 26, 1973, and after 180 days, comments will have been considered and a final document published. The predecessor of this criteria document is entitled "Water Quality Criteria" (the Green Book) and is the basis for current Federal criteria and State water quality standards. States have been active in the area of water quality standards for several years and in many cases have adopted standards more stringent than the Federal criteria.

Section 304 of the act requires the development of information including guidelines for identifying and evaluating the nature and extent of non-point sources of pollutants, and processes, procedures and methods to control pollution resulting from 1) mining activities, including runoff and siltation from new, currently operating, and abandoned surface and underground mines; 2) salt water intrusion resulting from reductions of fresh water flow from any cause, including extraction of ground water, irrigation, obstruction, and diversion, and 3) changes in the movement flow, or circulation of any "navigable waters" or ground waters, including changes caused by the construction of dams, levees, channels, causeways, or flow diversion facilities.

Section 305 of the Act required that on or before January 1, 1974, the Administrator of EPA submit to Congress a description of the specific quality during 1973 of all navigable waters and an inventory of all point sources of discharge of pollutants. This is to be followed by annual reports from each State which, among other things, describe the water quality of all "navigable waters" during the preceding year, the extent to which all "navigable waters" of that State provide for protection and propagation of a balanced population of shellfish, fish, and wildlife and for recreation, and a description of the nature and extent of nonpoint sources of pollutants. Thus, a continuous program for monitoring progress toward the State and national goals for water quality is another factor which shows that water quality standards are a very important constraint that must be recognized and reflected in any development project

From the above discussions it is easy to see that effluent limits for permits are a combination of technology based effluent limitations and water quality standard based effluent limitations. The FWPCA requires that all States have a continuous planning process which classifies each stream as either effluent standard limiting or water quality standard limiting so that permits can be issued. If flow in any stream were to be significantly altered because of a diversion or impoundment, all existing permits and plans which insure water quality may have to be abandoned and new ones developed. The additional cost involved should be internalized and quanitified so it can be considered as the constraint it truly is.

Planning

Aside from the functional authorities already highlighted, there are other important Congressional enactments in the field of water and related land resource development. The Water Resources Planning Act of July 22, 1965, authorized the President to establish River Basin

Commissions when requested by a majority of the governors of the affected States, and established the Water Resources Council composed of the Secretaries of the Interior, Agriculture, Army, Transportation Health Education and Welfare, and the Chairman of the Federal Power Commission. The Council was directed to maintain a continuing study and prepare an assessment biennially, or at such less frequent intervals as the Council may determine, of the adequancy of water supplies necessary to meet water requirements in each water resource region and the national interest therein; to maintain a continuing study of the relation of regional or river basin plans and programs to the requirements of larger regions of the Nation; and to assess the adequacy of administrative and statutory means for the coordination of the water and related land resources, policies, and programs of the several Federal agencies. Further, it was to appraise the adequacy of existing and proposed policies and programs to meet such requirements and make recommendations to the President.

On September 5, 1973, the President approved the Water Resource Council's "Principles and Standards for Planning Water and Related Land Resources." Under these multiobjective procedures, alternative plans are formulated for two objectives--national economic development and environmental quality.

An executive order establishing the Missouri River Basin Commission was issued by the President on March 22, 1972. The Commission serves as the principal agency for the coordination of Federal, State, interstate, local, and nongovernmental plans for the development of water and related land resources in the Missouri River Basin. The primary function of the Commission is to prepare and keep up to date a comprehensive coordinated joint plan for the Missouri River Basin. The Commission can recommend and coordinate long-range schedules of priorities for investigation, planning, and construction of projects.

POTENTIAL WATER RESOURCE DEVELOPMENT

Background

Water supplies for possible future use in the Upper Missouri River Basin are indirectly related to the flow of the river at Sioux City, Iowa. This point separates the upper basin from lower basin, the wet downstream States from the dry upstream States, and is the demarcation point between the head of navigation and the bottom of main-stem storage. At this point the average annual flow of Missouri River is 21,821,000 acre-feet at the 1970 level of development, and this flow is bolstered by 74.7 million acre-feet of storage in the six reservoirs located upstream on the Missouri main stem. Between Sioux City and the mouth of the river in Missouri, an average annual accretion of 31,429,000 acre-feet can be expected.

Any water which might be allocated to future industrial supplies for conversion of coal in the coal region will probably come from water at and upstream from Lake Sakakawea. This lake, behind Garrison Dam, is the largest of the six main-stem storage facilities, and has an average annual inflow of 16,952,000 acre-feet.

A practical limit of additional future depletions in the upper basin has been tentatively determined to be 9.9 million acre-feet per year above 1970 level. This 9.9 million acre-feet will more than supply all the projected depletions that have been made in any study undertaken to date. Even with the entire 9.9 million acre-feet consumed, there could still be partial service to navigation, a viable hydropower generating facility, and minimum flows throughout a decade long drought period, as experienced in 1930-1941, of 6,000 cubic feet per second between and from all main-stem reservoirs. (See report by Corps of Engineers, Missouri River Mainstem Reservoir Regulation Studies, Series 1-74, April 1974).

All the Missouri Basin States and interested Federal agencies have the privilege of reviewing proposed developments anywhere within the basin.

The main-stem reservoirs and their storages are:

Dam	Reservoir	State	Capacity in A.F.		Ave. Annual
			Total	Holdover	Inflow (AF)
Ft. Peck	Fort Peck	Mont.	18,900,000	10,900,000	6,838,000
Garrison	Lake Sakakawea	N. Dak.	24,200,000	13,400,000	16,952,000
Oahe	Lake Oahe	S. Dak.	23,500,000	13,700,000	18,525,000
Big Bend	Lake Sharpe	S. Dak.	1,910,000	270,000	18,525,000
Ft. Randall	Lake Francis Case	S. Dak.	5,700,000	2,200,000	19,118,000
Gavins Pt.	Lewis & Clark Lake	S. Dak.	520,000	195,000	20,394,000
	Total		74,730,000	40,665,000	

The first basin-wide prediction of future depletions was made in 1949 for use in a Missouri Basin Inter-Agency Committee report on Adequacy of Flows published in 1951. At that time it was estimated that eventual developments above Sioux City, Iowa, would cause 9.5 million acre-feet of depletion beyond 1949 levels.

The 1969 comprehensive Framework Plan for the Missouri River Basin gave justification for another complete updating of actual depletions and projected future depletions. This study predicted 11.6 million acre-feet of depletions beyond 1949 and 8.8 million beyond 1970 level of development. Neither the 1949 study nor the 1969 study predicted depletions great enough to need all the water physically available.

Current estimates include less water for irrigation and more for industry. The lower irrigation growth is predicated on several factors such as more detailed land classification results, higher interest rates, more difficult economic justifications for Federal projects, and National Water Commission's attitude concerning further irrigation development. Expected industrial needs are higher in the Northern Great Plains States because of the obvious interest in coal conversion. The current estimate of most probable depletions after 1970, including water for coal development, totals 7.5 million acre-feet and is about the same magnitude as earlier estimates. The first of the following charts (Figure 2) compares these three projections. The current projection is for the most probable rate or level of development, and the second chart (Figure 3) shows the expected uses which would cause the depletion in the current projection. As can be seen from Figure 3, the depletions which can be expected to result from coal development are a relatively minor part of the overall projected depletions above the 1970 level of development.

Water Availability

The Water Work Group has attempted to explore how much of the total water supply could be made available within or nearby the Fort Union-Powder Basin Coal Region and the storage that would be required. In so doing, the Work Group agreed that determinations would be based on meeting certain "instream flow requirements." However, in some cases it has proved impractical to meet these requirements.

Instream Needs

The flow rates necessary for instream requirements are difficult to assess. The amounts are intended to protect the aquatic, biologic, benthic, and esthetic values of a stream and preserve the existing fishery. While the concept is a good one, there is some disagreement between technicians on how to determine the needs. This is because

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Figure 2

COMPARISON OF PROJECTED STREAMFLOW DEPLETIONS ABOVE 1949 LEVEL OF DEVELOPMENT

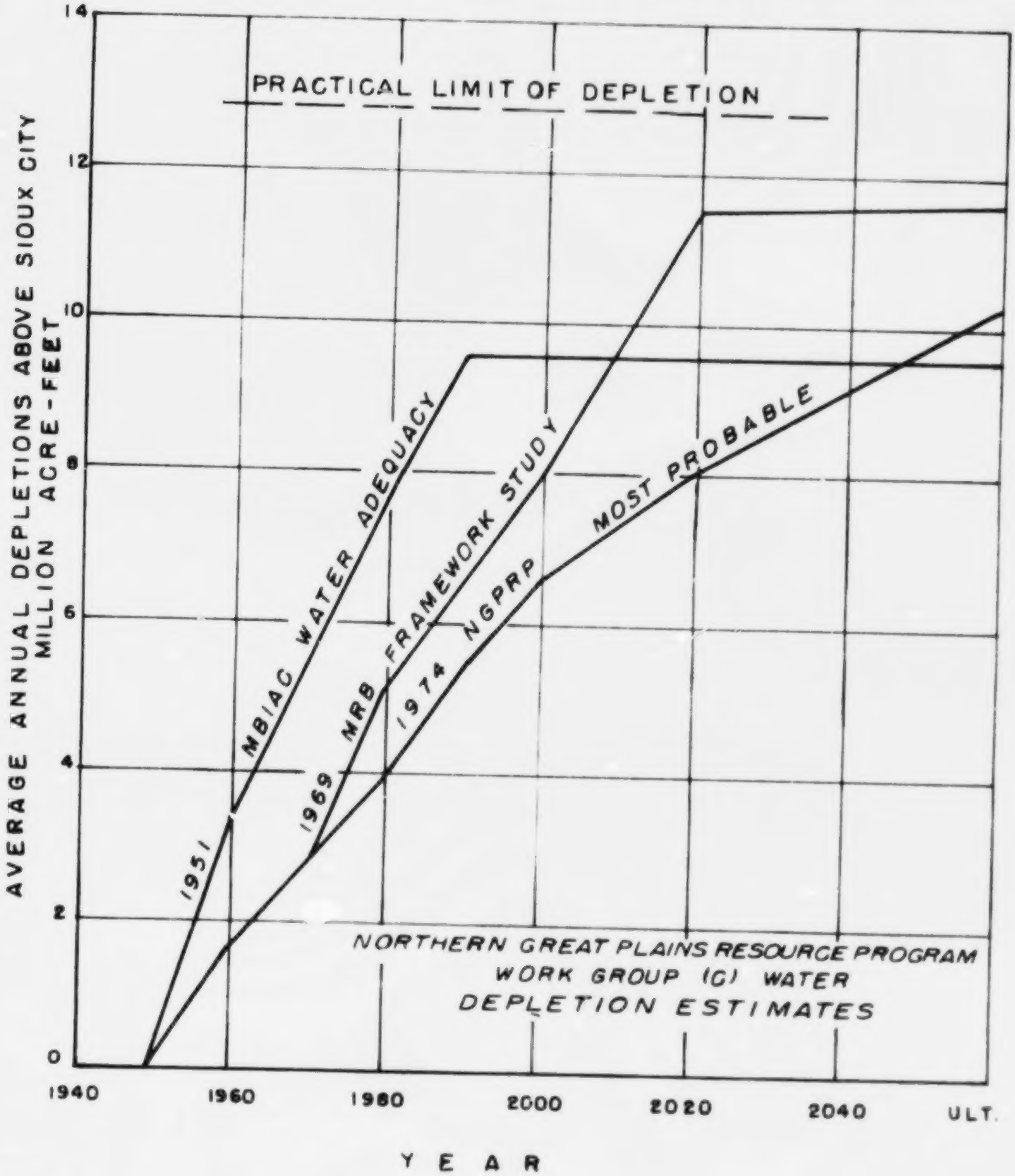
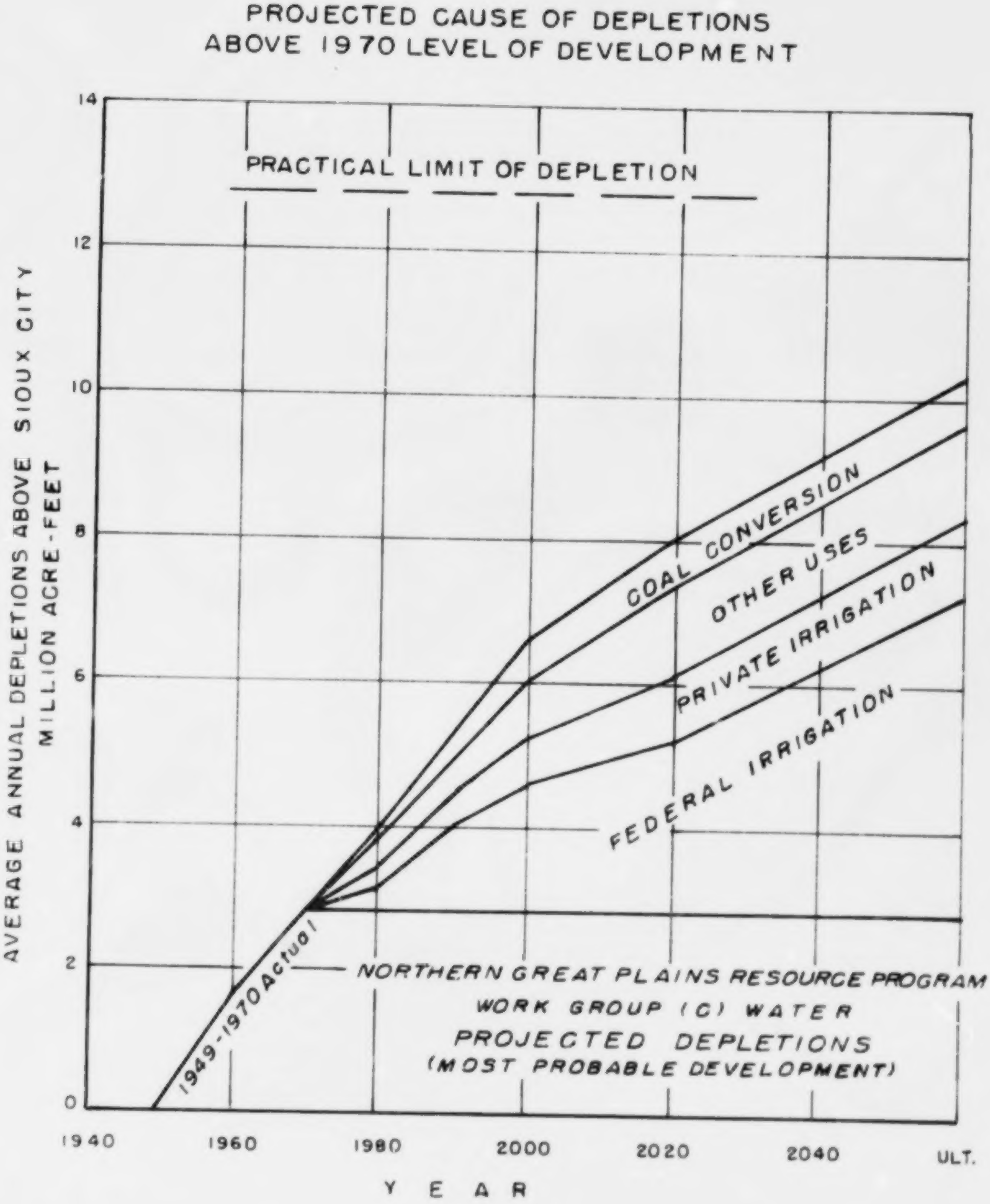


Figure 3


PROJECTED CAUSE OF DEPLETIONS
ABOVE 1970 LEVEL OF DEVELOPMENT
PRACTICAL LIMIT OF DEPLETION
COAL CONVERSION
OTHER USES
PRIVATE IRRIGATION
FEDERAL IRRIGATION
1949-1970 Actual
NORTHERN GREAT PLAINS RESOURCE PROGRAM
WORK GROUP (C) WATER
PROJECTED DEPLETIONS
(MOST PROBABLE DEVELOPMENT)
AVERAGE ANNUAL DEPLETIONS ABOVE SIOUX CITY
MILLION ACRE-FEET
0
2
4
6
8
10
12
14
1940
1960
1980
2000
2020
2040
ULT.
YEAR

of the wide variety of habitats and streamflow conditions, coupled with the general lack of research and detailed studies in this area. Further, the proposal to leave water in a river in most cases is too late in time to be practical; prior filings on water are in many streams already too numerous for natural flows to supply in dry periods.

The Water Work Group agreed that flow rates suggested by the Instream Needs Subgroup would be employed in determining water availability from streams in the study area. It was further agreed, in the context of this study, that success in meeting instream flows would erase adverse environmental impacts on the river reaches considered.

A summarization of instream flow rates suggested by the Instream Needs Subgroup is contained in the Instream Needs Appendix, along with the rationale and methods for deriving them.

Instream flow rates, if eventually adopted and imposed upon streams and rivers, will have a direct and major effect on streamflow available for other uses or for diversion to storage sites. The higher that an instream flow rate is fixed, the less water can be considered available for diversion and the greater becomes the required storage. In general, the amount of water available for storage or for new use will be reduced in the magnitude of 30 to 60 percent for any one selected storage volume and location if the instream flow rates are adhered to.

Water Availability Studies

Several potential storage sites were considered early in the water availability studies. Their locations are shown on Plates 1 and 2, and some data concerning the reservoirs is given in Table 4, following. The water availability studies were conducted to show total water available and are not directly related to the water supply studies in the coal development scenarios.

Water Availability by Basin.--All amounts of water discussed in this section as being available are in excess of current uses.

The amount of water available directly from Missouri River main-stem reservoirs is not exactly established, but it has been determined that up to 3 million acre-feet can be made available for coal processing, and meet all other projected water use needs, within the upper basin. The amount of water available from storage on the main stem of Missouri River is flexible because it is indirectly related to water depleted further upstream. Increasing the amount used upstream will diminish the amount available at the main-stem storage facilities. The storage now in operation on the Missouri River from Fort Peck downstream is sufficient and no further storage on the main stem would be required to supply whatever share of 3 million acre-feet might be needed directly from there.

Potential Water Resource Development

Total new water availability in Yellowstone Basin could be about 2 million acre-feet annually if suggested instream flows are fully satisfied and enough new storage is constructed. If instream flows were disregarded and replaced by a maintained minimum flow rate equal to 10 percent of the suggested flow rates, the entire 3 million acre-feet could become available annually in the Yellowstone Basin. These amounts will require construction of new storage reservoirs. Without new storage, only about 1 million acre-feet can be made physically available annually in the Yellowstone Basin, but suggested instream flows would not be satisfied during critical low-flow periods with a development level beyond the most probable.

The Western Dakota Tributaries, even with storage, can provide only minor amounts of water. In the water availability studies, certain of the potential reservoirs in the Yellowstone and Western Dakota Basins were selected and evaluated through detailed operation studies. The results of these evaluations are shown on Tables 5a through 5d which follow. The amounts of water shown as available are what would have been available annually during the critical period (driest period of record) without any shortages occurring; that is, the minimum that would have been available, though most of the time more would be available.

Also shown on Tables 5a through 5d are reservoir capabilities to supply water if instream values are ignored and replaced by releases needed only to meet existing uses plus a minimum flow equal to 10 percent of the suggested instream flow.

Use of Tables 5a through 5d and costs from Table 8 can be used to determine where and how much water could derive from new storage and at what cost. Because, however, we did not appraise or evaluate any of the environmental concerns at many of the reservoir sites, only an incomplete picture can be gained. It is possible to explore the financial cost of assisting Lake Bighorn after its capability is exhausted at some point beyond the most probable development level. It is also possible to directly compare the yield of a reservoir with and without the instream flow requirement, and to compare onstream and offstream sites.

More detailed information on the methods, procedures, and results of the reservoir and river operation studies is contained in the Water Availability Appendix.

No environmental analyses were made for most of the potential reservoirs or their operation because it was discovered during the study that most of them would not be needed for the coal development scenarios which are discussed in a later chapter.

Table 4

Potential Storage Sites

Sheet 1 of 2
June 1974

Name	Stream and Location	Drainage Area Sq. Mi.	Approximate Site Capacity - Acre-Feet				
			At Maximum	Flood Space Request	Sediment,* Dead and Inactive	Usable Conservation Space Without Flood Control	Usable Conservation Space With Flood Control
Wanigan	Yellowstone R. So. of Livingston, Montana	3,114	1,092,000	50,000	31,000		1,011,000
Allenspur	Yellowstone R. above Livingston, Montana	3,620	4,000,000	50,000	2,120,000		1,830,000
Absaroka	Yellowstone R. below Livingston, Montana	4,778	1,072,000	65,000	7,000*		1,000,000
Lissa	Yellowstone R. near Bighorn, Montana	37,315	2,405,000	1,500,000	180,000*	2,225,000	725,000
Buffalo Creek	Offstream near Custer, Montana	229	72,700	50,000	6,000*	66,700	16,700
Cedar Ridge	Offstream near Hysham, Montana	37	126,800	0	700*		126,100
Sunday Creek	Offstream near Miles City, Montana	716	678,000	125,000	14,000*	664,000	539,000
Lignite Creek	Offstream near Miles City, Montana	8	30,000	0	200*		29,800
Sweeney Creek	Offstream near Forsyth, Montana	99	116,000	0	2,000*		114,000
Moon Creek	Offstream near Miles City, Montana	66	150,000	0	1,300*		148,700
Tullock Creek	Offstream near Bighorn River, Montana	458	270,000	90,000	9,000*	261,000	171,000
Canyon Creek	Offstream near Billings, Montana	106	575,000	0	5,000		570,000
Wilsall	Shields River near Wilsall, Montana	445	81,000	80,000	4,500*	76,500	0
Shields R. Storage	Potter Creek near Wilsall, Montana	45	220,000	12,000	900*	219,100	207,100
Brackett Creek	Brackett Creek near Livingston, Montana	57	38,000	15,000	1,100*	36,900	21,900
Natural Bridge	Boulder River, Montana	236	35,000	35,000	750*	34,250	0
Rosebud Creek	Rosebud Creek 6 Mi. NE Colstrip, Montana	1,120	108,000	45,000	22,000*	86,000	41,000
Clarks Fork	**Clarks Fork Yellowstone River, Wyoming**	770	512,000		185,000	327,000	
Hunter Mountain	Clarks Fork Yellowstone River, Wyoming	164	130,000	35,000	6,760	123,240	88,240
Thief Creek	Clarks Fork Yellowstone River, Wyoming	484	200,000	90,000	10,000	190,000	100,000
Baldridge	Clarks Fork Yellowstone River, Wyoming	746	14,600	41,000	4,400	10,200	0
Sunlight	Sunlight Creek, Wyoming	134	50,000	30,000	2,000	48,000	18,000
Flatwillow	Flatwillow Cr. 2 Mi. from Musselshell River	1,840	70,800	0	24,000*		46,400
Custer	Bighorn River near Mouth, Montana	22,410	1,200,000	750,000	90,000*	1,110,000	360,000
Little Bighorn	Little Bighorn S.17, T.92, R.34E, Wyoming	210	65,000	45,000	4,000*	61,000	15,100
Buffalo Bill Enlgt.	Shoshone River above Cody, Wyoming	1,520	710,000	15,000	48,200	661,800	646,000
Owl Creek	Owl Creek near Lodge Grass, Montana	163	96,000	35,000	3,200*	92,800	57,800
Arvada	Powder River near Arvada, Wyoming	6,050	1,255,000	250,000	475,000*		530,000
Hole-in-the-Wall	Middle Fork Powder above Kaycee, Wyoming	455	55,000	0	10,000		45,000
Moorhead	Powder River near Moorhead, Montana	8,030	1,150,000	250,000	625,000		275,000
Pumpkin	Powder River near Pumpkin Creek, Wyoming	4,160	1,000,000	300,000	325,000		375,000
Lower Clear Creek	Clear Creek near Powder River, Wyoming	1,120	602,000	120,000	30,000*		452,000
Lower Crazy Woman	Crazy Woman Creek near Powder River, Wyoming	931	450,000	75,000	25,000*		350,000
Box Elder	Box Elder Creek near Ucross, Wyoming	32	54,500	8,000	700*	53,800	45,800
Rockwood	Tongue River 8 Miles SW Dayton, Wyoming	191	113,000	43,000	15,000	98,000	55,000
Stateline	Tongue River at Wyoming-Montana Line	1,115	203,600	108,000	90,000*	113,600	5,600
New Tongue	Tongue River at 4-Mile Creek, Montana	1,770	320,000	133,000	140,000*	180,000	47,000
North Prairie Dog	Prairie Dog Creek, near Mouth, Wyoming	358	39,900	9,900	30,000*	9,900	0
Mill Iron	Box Elder Creek near Baker, Montana	920	45,000	45,000	18,000*	27,000	0
Medora	Little Missouri near Medora, North Dakota	6,190	332,000	330,000	120,000*	212,000	0
Wagon Creek	Little Missouri near Camp Crook, South Dakota	2,245	230,000	119,000	45,000*	185,000	66,000
Marmarth	Little Missouri near Lower Coyote Cr., N. Dak.	3,930	504,000	370,000	75,000*	429,000	59,000
Deep Creek	4 Miles upstream from Lt. Missouri, N. Dakota	265	75,200	30,000	5,500*	69,700	39,700
Beaver	Beaver Creek 2 Miles from Mont. Line, N. Dakota	610	[illegible]9,000	65,000	8,000*	81,000	16,000
Broncho	Knife River, North Dakota	1,130	305,000	40,000	1,200		263,800
Emerson	Knife River near Crooked Creek, North Dakota	395	60,000	60,000	4,000*	56,000	0
New Versippi	Green River, Upper Axis, North Dakota	344	16,000	16,000	3,500*	12,500	0
Mott	Cannonball River above Mott, North Dakota	689	230,000	85,000	7,000*	223,000	138,000
Cannonball	Cannonball River near Mott, North Dakota	1,363	172,000	172,000	2,000*	170,000	0
Bently	Cannonball River 3 Mi. SE New Leipzig, N. Dak.	1,110	233,000	150,000	11,000*	222,000	72,000
Regent	Cannonball River near Regent, North Dakota	556	73,000	70,000	5,500*	67,500	0
Hettinger	Cedar River near Fordahl, North Dakota	562	31,500	30,000	5,500*	26,000	0
Thunderhawk	Cedar Creek, North Dakota	1,260	216,000	100,000	5,000	211,000	111,000
Bixby	Moreau River 1 Mile So. Bixby, South Dakota	1,570	379,000	125,000	3,800		249,200
Kendall	Green River, Wyoming	453	495,000	90,000	5,000		400,000
Lower Green	Green River, Wyoming	7,500	290,000		10,000	280,000	
Newcastle	Beaver Creek Near Newcastle, Wyo. (Cheyenne R.)	1,290	55,000	55,000	17,000*	38,000	0

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* Sediment only.

Table 4 (Continued)

Sheet 2 of 2

Potential Storage Sites

Name	Average Annual Inflow (A.F.)	Critical Year Inflow (A.F.)	Estimated Annual Sediment Inflow (A.F.)	Water Surface Acres At Normal Pool	Water Surface Acres At Minimum Pool	Estimated 1973 Costs (Dollars)	Estimated Ave. Ann F.C. Benefits 1973 Price Level (Dollars)
Wanigan	2,490,000	1,550,000		11,700	2,200	111,300,000	80,000
Allenspur	2,692,000	1,682,000	3,800	31,900	30,400	114,000,000	80,000
Absaroka	3,550,000	2,220,000	70	12,100	2,300	137,000,000	100,000
Lissa	7,810,000	4,000,000	1,400	40,000	11,000	109,000,000	230,000
Buffalo Creek	Negligible	Negligible	60	1,900	300	36,600,000	4,000
Cedar Ridge	Negligible	Negligible	7	4,700	120	24,210,000	0
Sunday Creek	Negligible	Negligible	140	13,700	4,300	113,000,000	10,000
Lignite Creek	Negligible	Negligible	2	770	20	15,930,000	0
Sweeney Creek	Negligible	Negligible	200	2,100	120	44,900,000	0
Moon Creek	Negligible	Negligible	13	3,150	700	50,240,000	0
Tullock Creek	Negligible	Negligible	90	3,500	500	64,080,000	7,000
Canyon Creek	Negligible	Negligible	50	6,200	50	90,000,000	0
Wilsall	90,000 Est.	Unknown	45	2,800	1,000	17,760,000	10,000
Shields R. Storage	9,000 Est	Unknown	9			18,970,000	1,000
Brackett Creek	12,000 Est.	Unknown	11	5,300	600	13,900,000	1,000
Natural Bridge	275,000 Est.	Unknown	7.5			3,200,000	4,000
Rosebud Creek	15,000 Est.	Unknown	220	2,400	1,100	19,920,000	20,000
Clarks Fork	658,000	438,000	730	460	320	75,000,000	
Hunter Mountain	236,000	166,000	160	1,900	170	16,705,000	4,000
Thief Creek	489,000	312,000	310	1,160	230	44,230,000	10,000
Baldridge	629,000	418,000	120	220	140	9,975,000	2,000
Sunlight	88,000	66,000	140	1,550	150	4,130,000	4,000
Flatwillow	2,550,000	1,429,000		2,300	1,200	17,630,000	0
Custer	110,000 Est.	60,000	900	21,300	4,500	25,000,000	300,000
Little Bighorn			40	1,150	180	27,950,000	10,000
Buffalo Bill Enlgt.				9,780	1,560	26,250,000	8,000
Owl Creek			32	1,900	200	17,870,000	9,000
Arvada	185,080	46,400	4,750	18,000	13,900	72,400,000	100,000
Hole-in-the-Wall	53,380	33,930	100	1,180	280	11,850,000	0
Moorhead	322,020	70,400	6,250	18,500	6,200	58,200,000	270,000
Pumpkin	128,380	34,640	3,250	12,000	19,200	62,600,000	90,000
Lower Clear Creek	129,280	34,540	300	8,300	3,500	37,100,000	6,000
Lower Crazy Woman	27,150	3,440	250	6,700	3,200	40,300,000	17,000
Box Elder	60,930	23,070	7	1,160	290	29,460,000	1,000
Rockwood	127,000	72,000	150	560	180	51,000,000	11,000
Stateline	307,000	137,000	900	5,260	700	27,467,000	105,000
New Tongue	300,000	110,000	7,400	7,600	250	42,750,000	140,000
North Prairie	23,000	4,600	300	1,285	270	17,030,000	22,000
Mill Iron	57,000	4,700	260	1,350	70	8,885,000	15,000
Medora	319,500	20,200	1,750	18,700	6,500	34,240,000	36,000
Wagon Creek	100,600	2,800	650	5,100	2,300	19,970,000	36,000
Marmarth	179,000	8,400	1,010	4,950	1,300	11,530,000	44,000
Deep Creek	10,500	100	75	1,740	200	4,390,000	2,000
Beaver	21,400	200	175	1,920	250	5,400,000	4,000
Broncho	44,000	2,000	110	5,300	700	11,293,000	50,000
Emerson	20,000	900	40	2,660	363	3,517,000	34,000
New Versippi	26,800	1,600	40	960	400	9,000,000	4,000
Mott	32,000	1,000	30	10,800	650	21,980,000	60,000
Cannonball	54,000	4,700	60	3,900	680	10,536,000	100,000
Bently	51,300	4,000	50	4,450	650	9,474,000	80,000
Regent	23,200		25	2,375	360	9,330,000	60,000
Hettinger	15,000	270	25	1,680	380	3,313,000	20,000
Thunderhawk	32,000	600	50	5,150	1,000	12,376,000	30,000
Bixby	60,000	4,250		4,700	5,800	24,800,000	90,000
Kendall	370,000		50	15,000	3,000	26,150,000	40,000
Lower Green	1,200,000	435,800		8,641	1,005	31,963,000	
Newcastle	24,030	3,700		2,250	800	3,200,000	12,000

Revised 9/24/74

TABLE 5a

WATER AVAILABLE IN YELLOWSTONE BASIN

AT SINGLE POINTS OF DIVERSION

STREAM & Diversion Point	Storage Reservoir(s)	Total Storage Capacity (acre-feet)	Water Available During Critical Period Without Shortage	
			Providing Suggested Instream Flows (acre-feet/year)	Providing 10% of Sugg. Instream Flows (acre-feet/year)
YELLOWSTONE RIVER				
Miles City	Sunday Creek	678,000	957,000	3,703,000
" "	Tullock Creek plus above	948,000	1,243,000	3,988,000
" "	Moon Creek plus all above	1,098,000	1,330,000	4,145,000
" "	Cedar Creek plus all above	1,224,800	1,401,000	4,277,000
" "	Sweeney Creek plus all above	1,340,800	1,466,000	4,397,000
" "	Buffalo Creek plus all above	1,413,500	1,507,000	4,473,000
" "	Lignite Creek plus all above	1,443,500	1,520,000	4,505,000
" "	Lissa	2,405,000	1,944,000	5,161,000
" "	Bighorn Lake and Boysen Reservoir (both existing)	1,918,000 1/	484,000	3,349,000
" "	Hunter Mountain	200,000	331,000	2,746,000
" "	Thief Creek	130,000	224,000	2,998,000
" "	Sunlight	50,000	89,000	2,275,000
" "	Sunlight plus Hunter Mountain plus Thief Creek	380,000	572,000	3,367,000
" "	Clarks Fork	512,000	520,000	3,304,000
	Allenspur	4,000,000	1,483,000	4,738,000
Mouth of Armells Creek	Bighorn Lake and Boysen Reservoir (both existing)	1,918,000 1/	474,000	3,098,000
POWDER RIVER				
Moorhead Reservoir site	Moorhead	1,150,000	77,000	129,000
" " "	Lower Clear Creek	602,000	101,000	161,000
Box Elder Reservoir site	Box Elder	54,500	34,000	34,000
Arvada Reservoir site	Arvada	1,255,000	65,000	123,000
" " "	Lower Crazy Woman	450,000	27,000	62,000
Pumpkin Reservoir site	Pumpkin	1,000,000	32,000	65,000
" " "	Hole-in-the-Wall	55,000	24,000	46,000
TONGUE RIVER				
New Tongue Reservoir site	New Tongue	320,000	63,000	159,000
" " " "	Rockwood	113,000	29,000	83,000
Stateline Reservoir site	Stateline	203,600	46,000	119,000
North Prairie Dog Reservoir	North Prairie Dog	39,900	15,000	41,000
WIND-BIGHORN RIVER				
Custer Reservoir site	Bighorn Lake (exist.), Boysen (exist.) and Custer	2,743,000 1/	611,000	1,777,000
Hardin	Bighorn Lake and Boysen (both existing)	1,918,000 1/	353,000	1,417,000
Bighorn Lake	" " " "	1,918,000 1/	319,000	1,391,000
Boysen Reservoir	Boysen	802,000 1/	111,000	431,000

1/ Excludes exclusive flood control space.

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TABLE 5b

WATER AVAILABLE AT MILES CITY WITH 1.22 MILLION ACRE-FEET PER YEAR DIVERTED FROM BIGHORN RIVER [1/]

Storage Reservoir(s)	Total Storage Capacity (acre-feet)	Water Available During Critical Period Without Storage: Providing Sugg. Instream Flows [2/] (acre-feet/year)	Water Available During Critical Period Without Storage: Providing 10% Sugg. Instream Flows (acre-feet/year)
Sunday Creek	678,000	710,000	2,483,000
Tullock Creek plus above	948,000	915,000	2,768,000
Moon Creek plus all above	1,098,000	988,000	2,925,000
Cedar Creek plus all above	1,224,800	1,049,000	3,057,000
Sweeney Creek plus all above	1,340,800	1,106,000	3,177,000
Buffalo Creek plus all above	1,413,500	1,119,000	3,253,000
Lignite Creek plus all above	1,443,500	1,130,000	3,285,000
Lissa	2,405,000	1,323,000	3,941,000
Hunter Mountain	200,000	134,000	1,526,000
Thief Creek	130,000	204,000	1,778,000
Sunlight	50,000	49,000	1,055,000
Sunlight plus Hunter Mountain plus Thief Creek	380,000	350,000	2,147,000
Clarks Fork	512,000	325,000	2,084,000
Allenspur	4,000,000	400,000	3,653,000

[1/] Bighorn water diverted at Bighorn Lake or downstream.

[2/] Suggested instream flows would not be provided between diversion point on Bighorn River and mouth of Bighorn River, but would be provided at all other places.

TABLE 5c

WATER AVAILABLE IN YELLOWSTONE BASIN

WITH MULTIPLE POINTS OF DIVERSION

Reservoirs	Storage Capacities[1/] (acre-feet)	Points of Diversion		Water Available During Critical Period without shortage; Suggested instream flows provided (acre-feet per year)
Boysen (existing)	802,000	at reservoir		111,000
Bighorn Lake (existing)	1,116,000	at reservoir		208,000
Total	1,918,000		Total	319,000
Boysen(existing)	802,000	at reservoir		111,000
Bighorn Lake(existing)	1,116,000	at reservoir		223,000
Clarks Fork	512,000	Miles City		415,000
Total	2,430,000		Total	749,000
Boysen(existing)	802,000	at reservoir		111,000
Bighorn Lake(existing)	1,116,000	at reservoir		223,000
Allenspur	3,950,000	Miles City		1,510,000
Total	5,868,000		Total	1,844,000
Boysen(existing)	802,000	at reservoir		111,000
Bighorn Lake(existing)	1,116,000	at reservoir		223,000
Clarks Fork	512,000	Miles City		1,722,000
Allenspur	3,950,000			
Total	6,380,000		Total	2,056,000

1/ Excludes exclusive flood control space.

TABLE 5d

WATER AVAILABLE FROM WESTERN DAKOTA TRIBUTARIES

Location of Storage (River Basin)	Reservoir	Total Storage Capacity (acre-feet)	Water Available During Critical Period Without Shortage 1/	
			Providing Suggested Instream Flows (acre-feet per year)	Providing 10% of Sugg. Instream Flows (acre-feet per year)
Little Missouri	Marmarth	504,000	26,000	53,000
	Medora	332,000	54,000	100,000
	Wagon Creek	230,000	25,000	34.000
	Beaver	89,000	2,000	2.000
	Mill Iron	45,000	5,000	13,000
Knife	Broncho	305,000	17,000	23,000
Heart	--	--	Negligible	--
Cannonball	Mott	230,000	13,000	21,000
	Thunderhawk	216,000	12,000	21,000
	Cannonball	172,000	22.000	35,000
Grand	Shadehill (existing)	139,700	0	Negligible
Moreau	Bixby	253,000	23,000	26,000

1/ Diversion from reservoir in all cases.

In summary, the Missouri main-stem reservoirs could directly yield a large portion of the 3 million acre-feet which could be made available annually for industrial uses. The Yellowstone Basin could yield 2 million acre-feet and still largely meet the instream flows recommended by the Instream Needs Subgroup if additional storage is constructed. However, Montana, Wyoming, and North Dakota all have strong feelings toward developing more irrigable agricultural lands. If new agriculture is accommodated, water available for industry could be reduced. Allowing for future irrigation of those lands which appear feasible for development, industrial water availability from the Yellowstone Basin might be reduced by a few hundred thousand acre-feet.

Colorado Basin water, surplus to Wyoming's local need, might be available for export from the Green River into the Missouri Basin within Wyoming in some amount up to 300,000 acre-feet. Only the economic cost has been examined; other impacts have not been explored. Such a diversion would parallel I-80 to the Platte River and be rediverted near Douglas and continue to the Gillette vicinity.

Water from Weather Modification

Precipitation management technology has developed over the past several years. It is now well documented that precipitation augmentation is a feasible approach to increasing water supplies within many areas including a favorable outlook for results in the Fort Union-Powder Basin Coal Region.

Current potential increases in precipitation from seeding summer cumulus cloud formations are estimated to be as high as 25 to 30 percent in part of southern Montana. Miles City has been selected as one of three High Plains experiment areas for an extensive 5-to 7-year program.

The potential of winter orographic cloud seeding also looks promising for mountain areas. Water would not be available from this source directly onto the coal region, but could supplement winter snowpack on rivers which flow past or through the coal region.

Present estimates indicate that high quality water can be obtained through weather modification processes for about $2.50 per acre-foot. While technical solutions are well advanced, there are many problems to be resolved in the legal, social, and environmental fields. Research underway at several universities in the Northern Plains States already conclude that increased precipitation will result in increased crop and forage yields. Studies to date indicate no large effects on plant and animal communities would be anticipated with increased precipitation, and no adverse effects of silver iodide have been determined.

Potential Water Resource Development

Notwithstanding the apparent potential benefits from increased precipitation, there needs to be more study of the sociological, legal, and environmental implications of weather modification; thus, no quantifications of increased runoff or any suppositions as to possible uses for potential increase in precipitation have been made in this report.

WATER USES IN COAL DEVELOPMENT

Although coal development would result in various types of water use such as domestic use, mining use, and reclamation, this chapter deals only with the water used by coal conversion facilities, namely coal-fired electric powerplants and coal gasification plants. More detailed information than this chapter contains can be found in the report of the Subgroup on Water Quality.

Powerplants

The thermodynamic process employed to generate electricity has inherent limitations. For a typical new plant 9,000 BTU's of heat must be provided to generate one kilowatt-hour of electricity. The direct conversion is 3,413 BTU per kilowatt-hour. The remainder of the heat is waste heat, some of which goes up the boiler stack, and some of which must be removed from the steam which has gone through the turbine.

There are three basic methods of removing waste heat from the turbine exhaust steam: once-through cooling, evaporative cooling, and dry cooling. In once-through cooling, the excess heat is transferred from the steam to water which has been withdrawn from a river, pond, lake, or the sea, and the water is then returned to its source at a higher temperature. This cooling method requires very large amounts of water and powerplants using it are usually situated near a river, lake, or the ocean. In evaporative, or wet cooling, the excess heat is transferred to water wich is then exposed to air so that much of the heat is used as some of the water evaporates. This method also requires large amounts of water. In dry cooling, the heat is transferred to the air without evaporation of water. As a "rule of thumb," about 95 percent of total powerplant water usage is for the cooling system when wet evaporative cooling is used. Most powerplants in the United States use either once through or evaporative cooling because of the high cost of dry cooling.

Water is also the working fluid in the boiler-turbine-condenser cycle. This water must conform to precise chemical specifications and is. therefore, treated extensively prior to use. Ash generated when coal is burned is usually sluiced with water to a pond for disposal. Water is also used to clean equipment, for domestic uses at the plant, for cooling minor equipment, and in air pollution control devices such as scrubbers.

Evaporative Cooling Systems

Figure 4 is a schematic water flow diagram for a typical wet cooling tower system. The water quantity requirements for water flows in the figure depend on three factors:

1. Makeup water quality.
2. Plant characteristics.
3. Water conservation practices.

Makeup Water Quality.--Makeup water quality determines the maximum cycles of concentration (cycles) at which the system can operate without water treatment. The term cycles is defined as the number of times that makeup water constituents are concentrated in the recirculating water. The constituents are concentrated due to the evaporation process. As more evaporation occurs, the solubility limits of the constituents are approached. Also, temperature changes that occur in the system affect the solubility of the constituents. If the solubility of one or more of the constituents is exceeded, cooling system fouling may result. Blowdown serves to keep the recirculating water within acceptable limits.

The makeup (M), blowdown (B), and evaporation (E) rates are related to the maximum cycles of concentration (c) by the following equations. (The equation symbols are from Figure 4.)

$$M = Bc \tag{1}$$

$$E = B\ (c-1) \tag{2}$$

The blowdown rate normally includes the tower drift losses. Drift losses are negligible when cycles are fewer than 20.

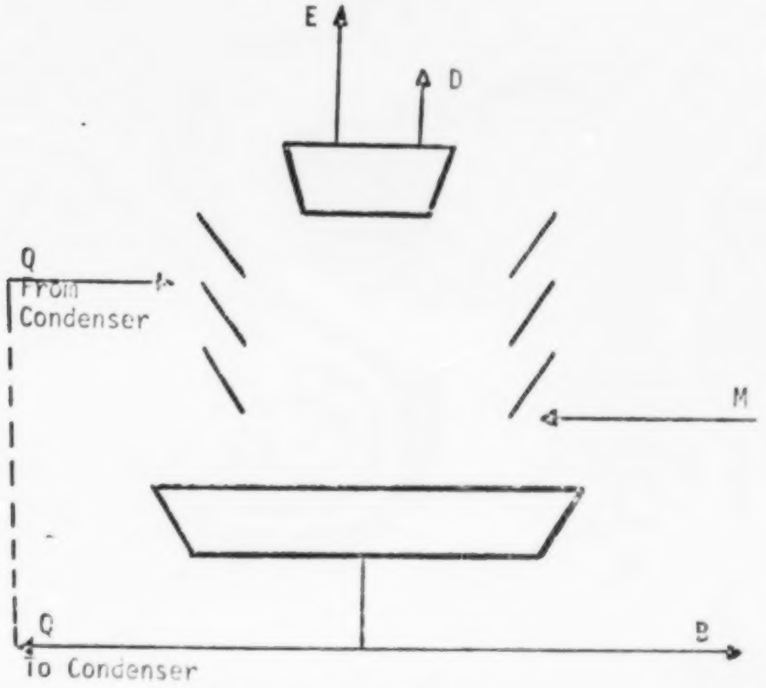
Plant Characteristics.--The plant characteristics that effect cooling system water requirements are:

a. The plant size.
b. The waste heat to cooling water.
c. The temperature use across the condenser.
d. The fraction of waste heat discharged by the cooling tower via latent heat vaporization.
e. The heat capacity and latent heat of vaporization of water in the system.

Water Conservation Practices.--Cooling system water conservation has one main goal--reducing makeup requirements. Makeup replenishes evaporation and blowdown. For wet, evaporative cooling towers, the

Figure 4

Wet Cooling Tower System


E
D
Q
From
Condenser
M
Q
B
To Condenser

Where

B = Blowdown rate
M = Makeup rate
Q = Recirculating rate
E = Evaporation rate
D = Drift rate

evaporation rate cannot be controlled. Therefore, any water conservation practice, regardless of its efficiency, still leaves a makeup requirement to satisfy evaporation.

There are two levels of water conservation that may be used to achieve a reduction in blowdown or discharge which, in turn, reduces makeup:

Base level control--defined as:

1. Sulfuric acid addition for pH control;
2. Automatic pH control equipment; and
3. Automatic blowdown control.

Advanced control--defined as:

1. Warm lime softening for hardness control;
2. Polymer addition for scale control;
3. Hydrochloric acid for pH control where sulfuric acid addition may promote calcium sulfate scaling; and
4. Near horizon technology such as brine concentration processes for blowdown control which include evaporators, reverse osmosis units, and demineralizers.

Tables 6 and 7 show a range for total powerplants water requirements for a 1,000-MW plant using Yellowstone or Missouri River makeup water. A range is given depending on the type of water reuse and water conservation programs employed. Additional water can be used at a plant if reuse is not practiced. Additional water use would result in additional discharge. Water must also be provided for non-plant uses, evaporation in surge ponds, percolation, etc. A plant bringing in 19,000 acre-feet annually would need to discharge on the order of 5,000 acre-feet per year.

Dry Cooling System

In some powerplants in Europe (and one in the United States, in the Gillette, Wyoming, area) and in many industrial plants throughout the world, dry cooling is used. Using the guideline discussed in the previous section, 95 percent of the water needs of a plant utilizing wet cooling is for the cooling system; as little as 500 acre-feet per year of water may be needed for plants utilizing dry cooling.

In general, plants utilizing dry cooling cost more. Different turbines, which can operate at higher back pressures, are needed. Dry cooling towers have been used on small plants to some extent but have not been designed and applied to large installations. Even if and when developed for large scale plants, their use has extreme penalties on an operation, i.e. reduced plant efficiencies, higher heat rates, additional power requirements, additional fuel requirements, lower plant reliability, and higher capital costs. Water supply would have to be extremely limited to warrant imposing the penalties associated with dry cooling on the public.

Coal Gasification

Although techniques for the manufacture of low BTU gas from coal are well established, technology for upgrading the fuel gas to the quality of pipeline gas is in the early stages of development. As such, many questions regarding the resource requirements for a plant producing substitute natural gas are unanswered.

The two major resources required for a coal gasification industry are coal and water. Requirements for the former may be estimated with a fair degree of accuracy given the chemical composition of the coal and the projected plant size. Quantification of the water demand, however, involves more variables, several of which revolve around technology yet to be developed. Nevertheless, estimates of anticipated water usage have been made by process developers and plant designers. Of the several potential pressure gasification processes under various sponsorship, only that licensed by Lurgi Mineraloltechnik has attained the design stage for commercial application. As such, the Lurgi serves a base with which to estimate the requirements for water and the potential changes in those requirements.

Water Uses in Coal Gasification

Water is a primary resource required for synthetic gas production. It is used in both processing and cooling. In processing the water is used to generate steam and supply hydrogen for the reaction. It is also used for ash quenching and sluicing and for dust control and other applications in the mined areas. Because many of the reactions are highly exothermic, extensive process cooling is required.

Estimated Water Requirements

Several studies have been conducted to provide estimates of water requirements of a coal gasification industry. Nearly all the estimates

Table 6

Annual Powerplant Water Requirements
Yellowstone River Water *

(1,000-MW Plant - Wet Cooling)

Level of Cooling System Control	With SO_x Scrubbers: Intake Requirements (Acre-Feet)	With SO_x Scrubbers: Discharge Requirement (Acre-Feet)	Without SO_x Scrubbers: Intake Requirement (Acre-Feet)	Without SO_x Scrubbers: Discharge Requirement (Acre-Feet)
Base Level Control	10,800-14,000	0-3,485	10,800-11,400	2,600-3,500
Advanced Control				
HCl Addition	10,800-13,140	0-2,650	9,950-10,500	1,750-2,650
Polymer Addition	10,800-12,500	0-2,024	9,330-9,900	1,130-2,020
Blowdown Lime Softening	10,800-11,400	0-920	8,220-8,800	30-900
Blowdown Brine Concentration	10,800-11,000	0-570	8,200-8,450	0-570

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* In all columns: Low number reflects maximum water reuse; high number reflects minimum water reuse.

Table 7

Annual Powerplant Water Requirements
Missouri River Water *

(1,000-MW Plant - Wet Cooling)

	With SO_x Scrubbers		Without SO_x Scrubbers	
Level of Cooling System Control	Intake Requirement (Acre-Feet)	Discharge Requirement (Acre-Feet)	Intake Requirement (Acre-Feet)	Discharge Requirement (Acre-Feet)
Base Level Control	10,800-13,900	0-3,300	10,700-11,250	2,500-3,320
Advanced Control				
HCl Addition	10,800-13,150	0-2,650	9,950-10,500	1,750-2,640
Polymer Addition	10,800-12,650	0-2,140	9,450-10,000	1,640-2,140
Blowdown Lime Softening	10,800-11,400	0-930	8,250-8,800	45-930
Blowdown Brine Concentration	10,800-11,100	0-560	8,200-8,400	0-560

* In all columns: low number reflects maximum water reuse; high number reflects minimum water reuse.

assume a plant production capacity of 250 million cu.ft./day. Because there are no prototype installations for producing pipeline quality gas from coal, estimates of water consumption for such an operation must be based on preliminary information. The number of variables which can influence the plant requirements for water include the composition of the feedstock, the character of the effluents and means for recycling them, the type of power cycle employed, and the feasibility of air cooling. On the basis of presently available information, it can be estimated that a coal gasification plant using the Lurgi Process and producing 250 MM scf/day of substitute natural gas will require 6,000 to 10,000 acre-feet of water per year: however, some companies indicate that up to 17,000 A.F. may be required.

The ability of the plant designer to achieve the lower limit will depend on the development of techniques to recycle the process condensate and maximum use of air cooling. The startup of announced plants and the continuation of ongoing research in process development will provide much information to quantify water consumption for a given system and feedstock. Ultimately, the water demand for a particular plant will be highly dependent on the ingenuity of the plant designer and the availability of raw water makeup.

Coal gasification will require less water per unit of energy produced than does thermal electric generation. Disregarding byproducts, the energy contained in the product gas is about 2.5×10^5 BTU for each cubic foot of water consumed in the gasification process. Putting it in terms of the electrical equivalent, this is about 14 cubic feet of water per megawatt-hour. This may be compared with the water required for conventional steam electric power generation, which with evaporative cooling, is typically about 70 cubic feet per megawatt-hour.

The gasification processes also promise to be more efficient in the utilization of coal resources than is conventional power generation. Again, disregarding the energy content of the byproducts, the conversion of coal to gas will be about 60 percent efficient. This is compared with an efficiency of 38 percent in a fossil-fuel powerplant. Of course, any comprehensive comparison of the two forms of energy conversion must consider a much wider range of variables.

Water Supply for Coal Development Scenarios

WATER SUPPLY FOR COAL DEVELOPMENT SCENARIOS

Annual water requirement for each scenario was based on 19,000 acre-feet for each 1,000 megawatts of power and 30,000 acre-feet for each gasification plant. All gasification plants were the same capacity - 250 million cubic feet per day of synthetic natural gas.

Each gasification plant is expected to consume 10,000 acre-feet and return 20,000 acre-feet annually of water having suitable quality for other uses. This procedure will permit water cooling at the installation and provide water for other uses in the general vicinity of the plant site. Other uses would probably be primarily for new irrigated agriculture, in line with the desire of the States to remain agricultural, but could also satisfy municipal, fishery, recreational, and mine reclamation needs.

Powerplants receiving 19,000 acre-feet annually would be able to water cool the facility. Consumption is expected to be 14,100 acre-feet and produce an effluent of 4,900 acre-feet. Return water in this case would be more highly concentrated in TDS and unusable for other purposes until discharged into a stream and diluted to a suitable quality. This will be possible in most instances because the amount of effluent is reasonably small.

The scenarios were all handled in the manner explained and the water quality chapter analyzes, for the first choice, the impact of this approach. If costs for water delivered in this manner are too high, dry cooling may become advantageous. With dry cooling, we could anticipate smaller quantities of water at a still higher unit cost, less impact on water and land, and lost opportunity for irrigated agriculture in the mining vicinity. A company making decisions on choice of cooling would balance the water cost and water needs for each choice, together with the advantages and penalties associated with design and operation.

A description of each level of development and the source of water for each plant location is discussed in the text following. The scenarios with their choices and alternatives are shown on Plates 5 through 14.

Base Level of Development

The Base Scenario shows a total of six coal-fired powerplants requiring 124,000 acre-feet of water. Two choices were examined. The first choice requires Moorhead Reservoir with 23,000 acre-feet taken to Wyoming (Site P-1) through 33 miles of small pipe at a rate of 33 c.f.s.

A reservoir operation study utilizing 23,000 acre-feet for industry was made and appraised. The choice also requires New Tongue Reservoir to supply three plants in Montana near the Tongue River. A reservoir operation was made to provide 63,000 acre-feet. Industrial water needs for the three plants total 58,500 acre-feet with 4,500 acre-feet to cover seepage losses in the river between the dam and Site P-4, some 25 miles downstream. About 17 miles of small pipe would be required to serve the three separate units. Plant P-5, near Fort Peck Reservoir, would pump 19,500 acre-feet from the impoundment and convey it at a rate of 28 c.f.s. through about 24 miles of small pipe to the plant site. Powerplant P-6, in North Dakota, would pump from the Missouri River about 15 miles below Garrison Dam and use water released from Lake Sakakawea. Only 3 miles of pipe would be required to convey 33 c.f.s. (23,000 acre-feet annually) to the 1,200-MW plant site. Appraisals of impacts at Fort Peck and at Lake Sakakawea show negligible effect. Their operations would not change, and the downstream flow reduction would hardly be discernible with the new diversions.

The second choice for Base Development does not change for P-6 in North Dakota. Plant P-5 near Fort Peck was served from Flatwillow Reservoir near Musselshell River. Its long pipeline and reservoir costs were much higher than in Choice 1, and P-5 should be served from Fort Peck in every alternate of every scenario. Wyoming Plant P-1 and Montana Plants P-2, P-3, and P-4 were investigated for service from existing Bighorn Lake on Bighorn River with an aqueduct system requiring 155 miles of small aqueduct.

Most Probable Level of Development

The Most Probable Scenario calls for 730,000 acre-feet of water annually. For the first choice, all requirements were served by aqueduct systems from existing storage except Plant P-1 in Wyoming where Pumpkin Reservoir site on Powder River was examined. Bighorn Lake would provide 321,500 acre-feet with 57 percent diverted at Hardin and the remainder near Forsyth at the mouth of Armells Creek. Fort Peck would provide 19,500 acre-feet to Plant P-5, and Lake Sakakawea would provide the remaining water needs of 357,000 acre-feet.

For the second choice under the Most Probable Scenario, all Wyoming requirements were served by two new reservoirs. Moorhead would supply 83,000 acre-feet and Box Elder Reservoir 30,000 acre-feet. In Montana, Fort Peck would be preferred over Flatwillow for Plant 5 and Bighorn Lake water diverted at Armells Creek would supply the remaining Montana requirements of about 338,000 acre-feet annually. In North Dakota, Mott Reservoir on Cannonball River was assumed to serve three plants totaling 69,000 acre-feet, while Lake Sakakawea served the remaining requirements totaling about 282,000 acre-feet.

Water Supply for Coal Development Scenarios

Extensive Level of Development

Water requirements for Extensive Development Scenario are twice as large as in the Most Probable Level of Development. Water to meet the 1,500,000 acre-feet can probably be made available with less impact and at less cost by extensive large aqueduct systems. No new storage appears necessary, but Bighorn Lake would be extensively used. Fort Peck would show negligible use, but Lake Sakakawea would be a substantial source of water.

Alternatives were examined for extensive development, mainly for Wyoming. For Wyoming, we predicted use of ground water, use of Green River, and service from Oahe Reservoir in South Dakota to determine the added cost of Article X of the Compact. Also examined were costs of diversion at Miles City for comparison with the Hardin-Gillette and Armells-Gillette aqueducts. Also, a reservoir on Little Bighorn was examined to serve one gasification plant (G-12) and Arvada Reservoir on Powder River was designed to serve three gasification units near Lake DeSmet (G-7, G-8, and G-9). These alternatives were not evaluated for environmental impacts.

Water requirements for the Extensive Development Scenario included water for domestic use of the increased population projected for the year 2000 due to coal development. These added amounts were 27,500 acre-feet for 127,000 people in a seven-county area in Montana; 23,000 acre-feet for 115,000 people in an eight-county area in Wyoming; and 36,000 acre-feet for 180,000 population increase in North Dakota over a wide area. Whether the municipal costs can be differentiated has not been examined.

Table 8 shows the cost per acre-foot of water delivered to each plant for all choices and alternatives under each of the three scenarios. More information on derivation of costs for the scenario water supplies is contained in the Scenario Water Supply Appendix.

Use of Ground Water

Use of deep-aquifer ground water was estimated. Insufficient data are available to closely determine availability and cost, but a hypothetical condition was assumed for one of the isolated gasification plants to ascertain approximate costs of recovering such water. Any large use of ground water would probably not be recharged and could thus represent use of a resource which may not be replenished. Spacing should be considerable between wells, and quality might vary within wide limits. Recovery of ground water may be essential to supplement other needs and in a few instances may be the most economic source. Additional study of this possibility may be warranted because the ground water potential is currently untested and unproven.

Table 8

SUMMARY OF WATER COSTS OF SCENARIOS PER ACRE-FOOT
Northern Great Plains Resource Program
Work Group (C) Water

Plant No.	Quantity of Water Delivered AF/Yr.	Base Forecast		Most Probable Forecast		Extensive Development Forecast						
									Alternative 3			Alternative 4
		Choice 1	Choice 2	Choice 1	Choice 2	Choice 1	Choice 2	Choice 3	North Dakota	Yellowstone basin	Gillette Area Transposed	Green River to Gillette Area Transposed
P-1	23,000	$115	$325	$230	$ 89	$189	$234	$	$	$260	$258	268
P-2	19,500	63	193	144	183	146	143			183		
P-3	19,500	74	209	165	162	168	127			155		
P-4	19,500	48	257	167	121	179	97			122		
P-5	19,500	80	296	80	296	80	80	80	80	80	80	
P-6	23,000	38	38	89	54	64	26	Excluded	61	Excluded	Excluded	
P-7	23,000	Not a part of this scenario	Not a part of this scenario	222	95	199	192		200			
P-8	23,000			175	124	152	144		151			
P-9	23,000			102	152	95	173		94			
P-10	23,000			140	104	116	78		114			
P-11	23,000			198	216	182	184		184			
G-1	30,000			176	275	378	203	45	Excluded from this alternative	318	311	201
G-2	30,000 acre-feet to each plant			310	133	268	328	256		307	300	207
G-3				210	66	238	290	217		293	287	218
G-4				118	199	224	274	201		283	276	232
G-5				93	268	206	253	180		270	267	241
G-6				124	126	206	253	180		270	267	241
G-7				74	70	195	277	143		217	304	230
G-8				47	43	189	271	109		211	290	250
G-9				151	134	161	243	140		183	279	244
G-10				50	52	133	152	183		195	Excluded from this alternative	Excluded from this alternative
G-11				50	52	133	152	183		195		
G-12				50	52	92	298	113		342		
G-13				53	79	47	84	172		84		
G-14				47	88	47	84	172		84		
G-15				35	28	47	84	172		84		
G-16				35	26	47	84	172		84		
G-17				Not a part of this scenario	Not a part of this scenario	118	88	168		87		
G-18						97	68	146		67		
G-19						76	47	134		47		
G-20						76	47	134		47		
G-21						76	47	134		47		
G-22						105	76	135		75		
G-23						154	95	92		104		
G-24						154	95	92		104		
G-25						109	133	Excluded from this alternative	110	Excluded		
G-26						49	76		49			
G-27						49	76		49			
G-28						49	76		49			
G-29						49	76		49			
G-30						49	76		49			
G-31						49	76		49			
G-32						49	76		49			
G-33						49	47		50			
G-34						49	47		50			
G-35						40	66		40			
G-36						40	66		40			
G-37						51	49		51			
G-38						54	29		53			
G-39						80	32		79			
G-40						80	32		79			
G-41						80	32		79			
G-42	30,000					135	128		136			

8/c

If everything goes extremely well, the ground water recovery could be in the $50 to $60 per acre-foot price range. This would mean that all wells are good producers.

Assumptions:
Annual requirements - 30,000 acre-feet
10 wells @ 2,000 gpm each
Depth of drilling - 12,600 feet @ $20/foot
Average pumping head - 1,000 feet
Pumping energy - 8 mills per Kw-Hr
Quality - 1,500 ppm of TDS
Depth to water initially - 600 feet
Drawdown - 400 feet
Spacing - 10 wells within 5-mile radius

Costs:

Wells	$2,520,000
Pumps	550,000
Piping, valves surge, etc.	4,008,000
Terminal Storage	1,254,000
Field Costs	$8,332,000

With administrative costs, interest during construction, and amortized over 40 years at 8 percent, the capital cost would represent an annual cost of $968,000. Adding OM&R and pumping costs shows a total annual cost of $1,559,000 or $52 per acre-foot.

Further data on use of ground water is contained in the report of the subgroup on ground water entitled "Possible Development of Water from Madison Group and Associated Rocks in Powder River Basin, Montana-Wyoming."

IMPACTS OF WATER USE FOR COAL DEVELOPMENT

Water Quantity and Reservoir Impacts

Water supplies shown as available to new uses would have certain impacts on reservoirs and on streamflow.

Regardless of which scenario is under discussion, Fort Peck Reservoir will be called upon to supply 19,500 acre-feet annually. The reservoir operation will not be changed, but the average discharge of 9,450 c.f.s. will be reduced by 28 c.f.s. This change in the Missouri River from Fort Peck to Lake Sakakawea could not be discerned.

Irrespective of scenario, Lake Sakakawea would also operate essentially the same as always. Flows in the Missouri River below Garrison Dam would be reduced by the total amount of water used upstream. Of the current discharge level, which averages 23,420 c.f.s., water for coal conversion would diminish these flows by 124,000, 730,000, and 1,500,000 acre-feet annually. These values correspond to reductions of 171, 1080, and 2072 c.f.s. respectively. Maximum reduction of flow from the coal development would be less than 9 percent on the average and its impact would be minor at Garrison. Return flow from the above diversions would largely return above Oahe Reservoir.

The main-stem storage system would not provide as long a navigation season in some years, and generation would be reduced at the main-stem powerplants now operating. Effects are shown in Tables 9 and 10 for the Most Probable Development. Effects on navigation and main-stem hydrogeneration for the Base Projection and Extensive Development would be similar to values shown in the tables for Most Probable effects because other depletions than those caused by coal conversion are the principal cause of change in navigation and decline in generation.

Bighorn Lake behind Yellowtail Dam is in a different category than the main-stem reservoirs. The environmental impacts at Bighorn Lake will be more pronounced than at Fort Peck and Lake Sakakawea, but less so than impacts on other potential sites where inundation has not occurred. Bighorn Lake is part of the first choice in the Most Probable and the Extensive Development Scenarios, although not a factor in the Base Development.

The monthly operation studies of Bighorn Lake already reflect recreation and downstream flow needs. Future operation will not change because of coal development; the change will take place between Hardin, where the water for southern Montana-northern Wyoming could easily

Table 9

Effects of Projected Depletions on Navigation

Season Length in Months	Years of Expected Service for Projected Level of Development and Time Frame										
	Current Level	Most Likely Projection			Without Coal			1969 Framework Plan			
	1970	1980	2000	2020	1980	2000	2020	1970	1980	2000	2020
8	66	62	51	48	62	54	51	66	61	43	15
7.75		1		2	2			1		3	3
7.5		1		1		1			1		2
7.25					2		1	1			1
7	1	2	4			1	3	1		3	4
6.75				2		2		2	1	2	5
6.5	1		1			2	1			2	4
6.25						3			1		4
6	3			3			2			5	7
5.75	2	1	5	2	1	1	5		3	1	2
5.5	2	1	1	1	1	1			2	2	1
5.25			1	3	2	1	1		2		
5		3		1	1		2			1	1
4.75		2	1		4						1
4.5		2	2								
4.25				2		1				1	2
4.			7	5		7	7			7	6
Zero			2	5		1	2			1	13
Total No. of Years	75	75	75	75	75	75	75	71	71	71	71

Table 10

Effects of Projected Depletions on Hydropower

Year	Depletions In A.F. After 1970	Capability In Megawatts	Ave. Ann. Generation In Million Kw.Hrs.	Reduction in Generation By	
				Total Depletion	Coal Only
1970	0	1937	9346	0	0
1980	1,193,000	1897	9028	318	27
2000	3,754,000	1994	8158	1188	171
2020	5,231,000	1808	7451	1895	254

be diverted, and the mouth of the Bighorn River. In the Extensive Development Scenario, the "Instream Flow Requirement" cannot be met if the 800,000 acre-feet of water required is diverted at Hardin. The reach from Yellowtail Dam to Hardin will remain an excellent trout fishery reach for 41 miles, but the reach from Hardin to the Yellowstone River will not have all the instream water suggested during the critical period. The appraisal of damage shows that only about half of the recommended value will be met in the critical period, but fully met under average hydrologic conditions.

Because only the bottom reach of the Bighorn River will be impacted, the Yellowstone being essentially satisfied, it is believed that the minimum flow of about 800 c.f.s. in the critical period and full satisfaction in normal years will be tolerable, or at least more acceptable than constructing a new reservoir to satisfy the suggested instream flow rates.

Under the Most Probable Scenario, only 183,000 acre-feet will be diverted at Hardin, and the suggested "instream flow rates" can be met with no impact either adverse or improved.

Under the Extensive Scenario, one way to insure that minimum flows as suggested in the "instream flow rate" can be met through the entire Bighorn River reach is to make the diversion for coal processing at the mouth of Armells Creek or at Miles City. These points of diversion would allow more of the "instream flow rates" to be met in the Yellowstone, but there would be some deficiencies.

Bighorn Lake and its role need here to be explained. First, it is in operation and has a water right priority in Montana dated May 5, 1961. It also has the capability to supply 1,220,000 acre-feet annually to new uses if flow in the lower Bighorn is limited to a minimum of 200 c.f.s. during the critical period and if all existing uses downstream on both the Bighorn and Yellowstone are legally supplied as of 1961 conditions.

The suggested instream flow rates below Hardin, Montana, have ignored the fact that 80 percent of the surplus water belongs to Wyoming and that Wind River Reservation in the headwaters has a prior right to its future needs. Thus, while the effort to preserve the existing aquatic resource is worthwhile, there is no compelling reason for condemning failure to comply.

The Wind-Bighorn River can meet the instream flows up to a limit. That limit is essentially this:

Impacts of Water Use for Coal Development

Point of Diversion	Firm Annual A.F. per Year after Accommodating Instream Flow Rates Suggested
Boysen Reservoir	111,000
Bighorn Lake	319,000
Hardin	353,000
Armells Creek	474,000
Miles City	484,000

Under the Extensive Development scenario, Bighorn Lake was called upon to annually produce 801,500 acre-feet. This is (at Hardin) 448,500 more than possible if instream flows are met, but 220,500 less than the reservoir could legally and physically provide. (See duration curve on Figure 5.)

Our decision was that Bighorn Lake could supply the water needs even though suggested instream flows would not be met during the critical period. Requested flows could be met most of the time, however. If failure to provide both industrial water and instream flows is not acceptable, then new storage would be required. Being deficient by about 450,000 acre-feet, a new reservoir at any of the following locations would overcome the deficiency.

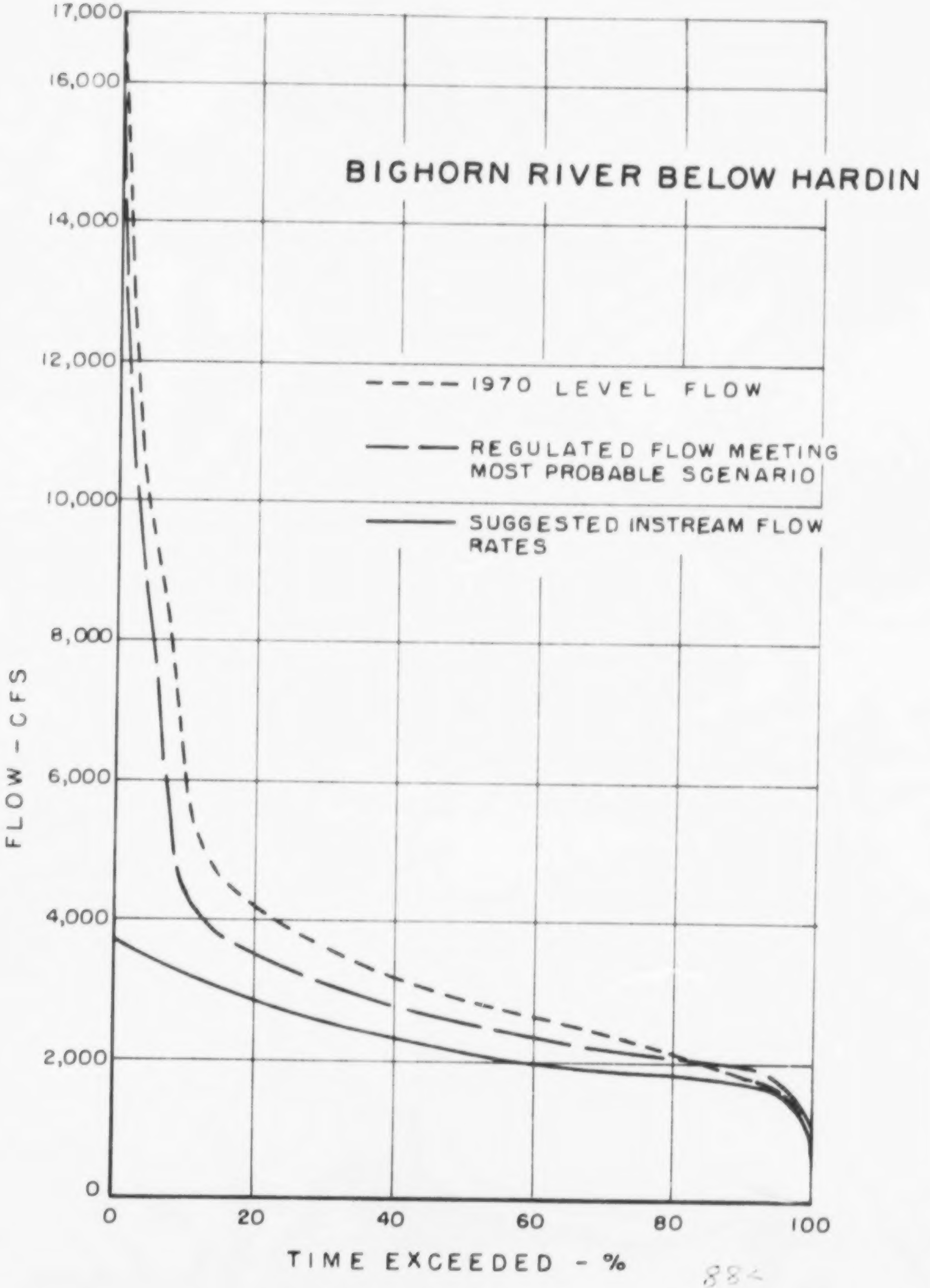
New Storage Site	Annual Yield After Meeting Suggested Instream Flows A.F. per Year
Clarks Fork	520,000
Sunday Creek	957,000
Allenspur	1,483,000
Lissa	1,944,000

Aside from the large reservoirs at Lake Sakakawea, Fort Peck, and Bighorn Lake, the potential reservoirs that have been appraised throughout the area are similar but will have impacts on wildlife habitat, river fisheries, and aesthetics.

The general findings throughout the Fort Union-Powder Basin Coal Region regarding potential reservoirs appears to be quite consistent. Every potential site has quality habitat for some particular species of big game and other animals, or for pheasants, grouse, and other birds. Some sites may be more critical than others, but habitat losses can be expected and will be irreplaceable.

Existing fisheries are, in general, only poor to fair throughout the rivers in the Dakotas and in the Powder and Lower Tongue Rivers.

Figure 5


BIGHORN RIVER BELOW HARDIN
1970 LEVEL FLOW
REGULATED FLOW MEETING MOST PROBABLE SCENARIO
SUGGESTED INSTREAM FLOW RATES
FLOW - CFS
17,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
20
40
60
80
100
TIME EXCEEDED - %

88<

although some areas have excellent population of such species as sauger or catfish. All support several species of fish and some of the rivers provide nursery areas and seasonal spawning areas. Construction of reservoirs could greatly improve the downstream fishery except that the water diversions proposed will preclude such improvement. By meeting instream values, the existing aquatic resource is essentially preserved and the downstream fishery will continue to be only poor to fair. Fair to good reservoir fisheries could be expected in most new reservoirs during the first few years after impoundment, but these could require intensive management to sustain good populations of desirable species. Flat water recreation would have importance in many of the river basins.

Rivers toward the west of the area provide good to excellent fishery qualities. Again, however, there would be but few opportunities to enhance a fishery below a reservoir except where storage intended for diversion could supplement the natural flow in the river system for some long distance upstream from the point diversion.

Aqueducts will be buried to prevent freezing and will have a temporary impact of some consequence. Some routes may cross pockets of high quality habitat where its loss could be ill-afforded. Some flexibility in alignment can be anticipated so that extreme local damage could be avoided. Within a few years, the vegetation should be satisfactorily recovered and the habitat would largely regain its former quality, even though it might differ some from the original. Maintenance roads and occasional structures would remain and result in a permanent loss of habitat amounting to about 3 acres per mile. Excavated earth would be graded into the right-of-way and dispersed with suitable topographic blending with the natural setting. Crossings through flowing streams will cause temporary degradation of water and possible loss of some aquatic organisms, but these effects can be minimized with proper precautions during cutting and backfill and assisted by care in selection of crossing site.

The monthly reservoir operation studies that were made did not always match the proposed diversion discussed in a given scenario. As an example, one scenario called for 23,000 acre-feet annually from Moorhead Reservoir and this operation study was made; but in another scenario for Moorhead the operation study showed 77,000 acre-feet divertible while meeting instream flow recommendations, but the scenario called for 87,000 acre-feet. Tongue River operation studies match the scenarios, but some others did not; the impact of the reservoirs were assessed based on the operation studies rather than the scenarios because time prevented matching them. Precise operation studies were made for some situations; but most reservoir impacts are more related to downstream river flow than to the impounded area. Reservoirs which have been appraised, and the expected impacts caused by their construction are shown in Tables 11 through 17 which follow:

Table 11

Moorhead Reservoir
(Powder River)

Storage		
Total Capacity	1,150,000	Acre-feet
Sediment and Dead	625,000	Acre-feet
Flood Control	250,000	Acre-feet
Conservation	275,000	Acre-feet
Inundation		
Acres Flooded	16,000	Acres
River Miles Flooded	35	Miles
Tributary Miles Flooded	8	Miles (Clear Creek)
Habitat Impact		
Big Game	High quality deer habitat lost, some important antelope habitat lost	
Game Birds	Medium quality bird habitat lost	
Reservoir Recreation Outlook	Good	
Downstream Flow Appraisal		
Flow	Instream flow recommendations met in one scenario, nearly met in other	
Existing Fishery	Poor	
Future Fishery	Fair	
Probable Water Quality Prediction	Improved	

Table 12

Arvada Reservoir

(Powder River)

Storage		
Total capacity	1,255,000	Acre-feet
Sediment and dead	475,000	Acre-feet
Flood control	250,000	Acre-feet
Conservation	530,000	Acre-feet
Inundation		
Acres flooded	13,900	Acres
River Miles Flooded	30±	Miles
Tributary miles flooded		
Habitat Impact		
Big Game	Loss of deer and antelope habitat	
Game Birds	Loss of bird habitat	
Reservoir Recreation Outlook	Good	
Downstream Flow Appraisal		
Flows	Meets instream flow recommendations	
Existing Fishery	Poor	
Future Fishery	Fair	
Probable Water Quality Prediction	Improved	

Table 13

New Tongue Reservoir

(Tongue River)

Storage		
Total Capacity	320,000	Acre-feet
Sediment and Dead	4,000	Acre-feet
Flood Control	0	Acre-feet
Conservation	316,000	Acre-feet
Inundation		
Acres Flooded	5,000	Acres
River Miles Flooded	12	Miles
Tributary Miles Flooded		
Habitat Impact		
Big Game	Loss of high quality deer habitat and low quality antelope habitat	
Game Birds	Loss of high quality sharp-tailed grouse and pheasant habitat, and medium quality sage grouse habitat	
Reservoir Recreation Outlook	Very good	
Downstream Flow Appraisal		
Flows	Instream flow requirements met	
Existing Fishery	Fair to good	
Future Fishery	Fair to good	
Probable Water Quality Prediction	No expected change	

Table 14

Pumpkin Reservoir
(Powder River)

Storage		
Total Capacity	1,000,000	Acre-feet
Sediment and Dead	325,000	Acre-feet
Flood Control	300,000	Acre-feet
Conservation	375,000	Acre-feet
Inundation		
Acres Flooded	16,000	Acres
River Miles Flooded	25	Miles
Tributary Miles Flooded		
Habitat Impact		
Big Game	High quality deer and antelope range lost	
Game Birds	Medium quality sage grouse habitat loss on about half the area	
Reservoir Recreation Outlook	Good	
Downstream Flow Appraisal		
Flows	Meets recommended instream	
Existing Fishery	Poor	
Future Fishery	Fair	
Probable Water Quality Prediction	Improved	

Table 15

Mott Reservoir
(Cannonball River)

Storage		
Total Capacity	230,000	Acre-feet
Sediment and Dead	7,000	Acre-feet
Flood Control	0	Acre-feet
Conservation	223,000	Acre-feet
Inundation		
Acres Flooded	11,000	Acres
River Miles Flooded	8	Miles
Tributary Miles Flooded		
Habitat Impact		
Big Game	High quality deer and antelope habitat lost	
Game Birds	High quality pheasant habitat Low quality sharp-tailed grouse habitat	
Reservoir Recreation Outlook	Good	
Downstream Flow Appraisal		
Flows	Would meet existing, but not the recommended instream flow	
Existing Fishery	Fair	
Future Fishery	Fair	
Probable Water Quality Prediction	Probable degradation unless effluents are zero	

Table 16

Flatwillow Reservoir
(Near Musselshell River)

Storage		
Total Capacity	70,800	Acre-feet
Sediment and Dead	24,000	Acre-feet
Flood Control	0	Acre-feet
Conservation	46,800	Acre-feet
Inundation		
Acres Flooded	5,000±	Acres
River Miles Flooded	5±	Miles
Tributary Miles Flooded		
Habitat Impact		
Big Game	Good habitat lost for white-tail deer Excellent habitat lost for fur-bearing animals	
Game Birds	Good habitat lost for pheasants	
Reservoir Recreation Outlook	Good	
Downstream Flow Appraisal	(New Operation studies not made)	
Flows	Suitable minimum flows into Musselshell River	
Existing Fishery	Poor	
Future Fishery	Fair to good	
Probable Water Quality Prediction	No expected change	

Table 17

Boxelder Reservoir
(Powder Basin)
Boxelder Creek Tributary of Piney Creek

Storage		
Total Capacity	54,500	Acre-feet
Sediment and Dead	700	Acre-feet
Flood Control	8,000	Acre-feet
Conservation	45,800	Acre-feet
Inundation		
Acres Flooded	1,300	Acres
River Miles Flooded	-	
Tributary Miles Flooded	8	Miles
Habitat Impact		
Big Game		High quality deer habitat would be lost Medium quality antelope habitat would be lost
Game Birds		Medium quality loss for sage and sharp-tailed grouse Low value loss for pheasant
Reservoir Recreation Outlook		Predict a good reservoir fishery, but the storage water will be from Piney Creek which could be seriously affected by diversion
Downstream Flow Appraisal		
Flows		Intermittent with or without reservoir
Existing Fishery		Low value
Future Fishery		Low value
Probable Water Quality Predictions		No expected change or slight improvement in Piney Creek

Water Quality Impacts of Coal Development

Water quality impacts of coal development have been predicted for total dissolved solids and dissolved oxygen for the first choice of each of the three scenarios used by the Northern Great Plains Resource Program to represent alternative levels of development.

There are other nonquantifiable impacts that may result from mineral and industrial development including: (1) water quality degradation from sediment carried into streams from stripped areas during periods of storm runoff, (2) water quality degradation from dewatering necessitated by high ground water table or storm runoff, and (3) groundwater degradation from increased water percolation through stripped areas and spoil piles.

Total Dissolved Solids

Total dissolved solids (TDS) is only one measure of water quality. It does, however, represent the sum of many important elements which can have harmful effects and is one of the water quality parameters defined in all State water quality standards.

The first step in the analyses was the determination of adjusted 1970 level average monthly flow and TDS concentration. Average monthly flows for station analyses were developed by the water work group for use in their river and reservoir operation studies. Table 18 is a summary of these data.

The existing TDS data for water quality stations in the study area were obtained and flow-TDS correlations were established from the data. With these data, average monthly TDS levels were established for the adjusted 1970 level flow. Table 19 is a summary of the data.

The approach taken to predict future TDS levels was simply to record the projected modification of future actions on either quantities of salt or quantities of water and recompute the resulting water quality. It was assumed for the purposes of this study that (1) return flows would return in the month it was diverted, and (2) water demand and return flows would be constant in each month of the year.

Base Scenario.--The first choice alternative for Base Level Development contemplates the construction of six thermal electric powerplants with two reservoirs and three aqueducts to store and deliver the water. One reservoir and three of the plants would be located in the Tongue River Basin; one reservoir and one powerplant

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Table 18

FLOW DATA FOR USE IN NGPRP WATER QUALITY EVALUATION

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
Bighorn River at Hardin													
1970 Level Flow	166.0	164.9	153.8	145.0	141.6	267.8	250.2	244.7	241.6	320.1	153.4	157.8	2,406.9
Adjusted for Indian & Other New Irrigation (59,000 Ac)	157.9	156.8	146.3	137.9	134.7	254.7	237.9	232.7	229.8	304.4	145.9	150.1	2,289.1
Bighorn River at Bighorn													
1970 Level Flow	171.7	173.6	159.7	151.3	153.1	299.7	273.7	267.6	276.8	318.8	146.3	158.1	2,550.4
Adjusted Future	163.6	165.5	152.2	144.2	146.2	286.6	261.4	255.6	265.0	303.1	318.8	150.4	2,432.6
Tongue River at State Line													
1970 Level Flow	13.1	12.8	10.4	9.5	10.7	18.9	21.4	62.9	92.3	23.5	6.8	9.2	291.5
Tongue River at Miles City													
1970 Level Flow	16.6	18.6	13.0	11.1	12.7	33.9	29.5	40.9	84.4	27.0	6.4	10.3	304.4
Powder River at Moorhead													
1970 Level Flow	11.2	11.9	10.2	8.6	13.7	40.7	32.8	60.5	87.7	27.5	9.4	7.6	321.8
Powder River near Locate													
1970 Level Flow	11.9	10.1	8.8	7.0	23.9	79.8	47.2	62.6	107.6	36.4	12.3	8.7	416.3
Yellowstone River at Miles City													
1970 Level Flow	464.2	420.6	350.2	317.7	329.1	582.3	557.9	993.7	1,909.7	1,271.1	482.5	423.2	8,102.2
Yellowstone River at Sidney													
1970 Level Flow	474.2	432.6	348.6	326.5	360.6	741.8	666.9	975.8	2,005.7	1,326.1	457.3	395.5	8,511.6

Table 19

1970 Level Water Quality (TDS) for Selected Streams
Northern Great Plains Study Area in ppm

Month	Bighorn River[1/] at St. Xavier	Bighorn River[1/] at Bighorn	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Miles City	Yellowstone River at Sidney	Missouri River at Bismarck
Oct	639	667	560	1510	500	524	
Nov	626	652	545	1480	510	537	
Dec	608	635	590	1540	570	579	
Jan	602	627	605	1570	595	590	
Feb	645	599	585	1430	560	560	
Mar	639	661	490	1200	450	458	
Apr	651	693	500	1240	450	470	
May	663	687	470	1120	355	421	
June	645	620	410	1050	255	336	
July	577	601	510	1290	310	386	
Aug	497	551	680	1550	505	528	
Sept	516	551	620	1600	510	550	
Avg	613	634	496	1226	396	444	441

[1/] Correlated data not utilized due to influence of storage on water quality. Quality based on depletions (adjusted historic) and historic distribution of salt released from reservoir. Flows at the 1970 level on the Bighorn River were reduced to reflect additional Indian and supplemental agricultural water depletions. Water quality was adjusted accordingly.

would be located in the Powder River Basin; one powerplant would be located on the Little Dry Creek Arm of Fort Peck Reservoir, and the sixth powerplant would be constructed in the Knife River Basin.

The following tabulation shows the water effects of the scenario:

	Drainage Basin							
	Powder River		Tongue River		Missouri River		Knife River	
	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion	Diversion	Depletion
Reservoir	51,700	51,700	13,300	13,300				
Powerplant								
1	23,000	17,100						
2			19,500	14,500				
3			19,500	14,500				
4			19,500	14,500				
5					19,500	14,500		
6							23,000	17,100
Total	74,700	68,800	71,800	56,800	19,500	14,500	23,000	17,100

Table 20 is a summary of the flow and TDS levels after Base Level development.

Most Probable Scenario.--The first choice plan for the Most Probable Level of Development includes the construction of five aqueducts and one reservoir.

One aqueduct would deliver water from the Bighorn River to two thermal electric powerplants and two gasification plants in the Tongue River Basin and one powerplant and two gasification plants in the Powder River Basin. Another aqueduct diverting water from the Yellowstone River at Armells Creek would supply water to three thermal electric plants on Armells Creek and one powerplant and one gasification plant on the Tongue River. A third aqueduct would supply one thermal electric powerplant from Fort Peck Reservoir to part of the Missouri River drainage in the Little Dry Creek Arm of Fort Peck Reservoir.

Two aqueducts from Lake Sakakawea would supply water to one thermal electric powerplant and five gasification plants in the Knife River;

one thermal electric powerplant in the Heart River Basin; three thermal electric powerplants in the Cannonball River drainage; and two gasification plants and one thermal electric plant returning water to the main stem of the Missouri River.

In total, the plan requires the diversion of 719,000 acre-feet of water for plant use and reservoir evaporation of an additional 42,600 acre-feet. Of this amount 423,900 acre-feet is consumed and 295,100 acre-feet returns to area streams.

Table 21 is a summary of the diversions and return flows from the first choice alternative of the Most Probable Forecast, and Table 22 is a summary of flow and TDS levels following Most Probable Development.

Extensive Development Scenario.--The first choice plan for Extensive Development includes a three aqueduct system to serve 11 thermal electric generating plants and 41 gasification plants. No new reservoirs would be required; although, extensive use would be made of waters impounded by Yellowtail and Garrison Dams and to a lesser degree Fort Peck Dam and Reservoir.

One aqueduct would supply water to four thermal electric plants and 24 gasification plants from the Bighorn River at Hardin. The plants would be located in the Sarpy Creek, Armells Creek, Tongue River and Powder River drainages. A second aqueduct would supply one thermal electric plant in the Little Dry Creek Arm of Fort Peck Reservoir from Fort Peck. The third aqueduct would supply water from Lake Sakakawea to seven powerplants and 17 gasification plants located in the Knife, Heart, and Cannonball drainages as well as the main stem of the Missouri.

Overall the plan requires the diversion of 1,469,000 acre-feet of water annually of which 881,300 acre-feet would return to the area streams and rivers and 587,200 acre-feet would be consumed. Table 23 is a summary of these data.

Table 24 is a summary of flow and TDS concentrations remaining after Extensive Level Development.

Bighorn River at Bighorn.--The impact of coal development on the water quality of the Bighorn River is not significant for any of the three scenarios. Average annual and monthly TDS for Base Level Scenario remains the same as the 1970 level. The Most Probable Development Scenario shows an increase of 3 ppm on an average annual basis increasing from 634 ppm to 637 ppm. Maximum individual monthly

Table 20

Summary Flow and TDS Levels After Base Level Development

Month	Flow Remaining (1,000 AF Units)						TDS Concentrations (ppm)					
	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck
Oct	163.6	456.1	15.5	6.1	462.7		667	500	682	2,470	538	
Nov	165.5	412.5	18.0	7.3	417.4		652	510	688	1,760	548	
Dec	152.2	342.7	12.6	6.3	334.4		635	570	694	1,760	590	
Jan	144.2	310.6	11.5	5.9	315.9		627	595	788	1,810	606	
Feb	146.2	322.2	11.5	7.9	343.1		599	560	577	1,600	564	
Mar	286.6	569.2	28.4	31.2	710.2		661	450	615	1,260	461	
Apr	261.4	545.6	25.0	24.9	639.9		693	450	585	1,333	473	
May	255.6	981.7	30.4	53.0	947.9		687	355	561	1,210	424	
June	265.0	1,897.9	51.4	77.6	1,955.2		620	255	499	1,130	337	
July	303.1	1,255.4	25.5	19.3	1,315.6		601	310	568	2,150	392	
Aug	138.8	475.0	7.8	4.3	448.5		551	505	755	2,930	538	
Sept	150.4	415.5	10.0	3.3	380.4		551	510	832	2,100	583	
	2,432.6	7,984.4	247.6	247.1	8,271.2	16,229.8	634	396	609	1,404	451	444

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Table 21

Summary of Diversions and Return Flows in 1,000 AF Units
Most Probable Development, First Choice

	Plant No	Diversions	RETURN FLOW Bighorn at Bighorn	Sarpy Creek	Armells Creek	Tongue River	Powder River Above Moorhead	Powder River Below Moorhead	Missouri River above Bismarck	Knife River	Heart River	Cannonball River	Cheyenne River
Bighorn River													
Electric Plant	1	23,000						5,900					
	2	19,500				5,000							
	3	19,500				5,000							
Gasification	2	30,000						20,000					
	3	30,000					20,000						
	4	30,000				20,000							
	5	30,000				20,000							
Total Bighorn		182,000				50,000	20,000	25,900					
Yellowstone River													
Thermal Electric	4	19,500				5,000							
Gasification	6	30,000		20,000									
	7	30,000			20,000								
	8	30,000			20,000								
	9	30,000				5,000							
Total Yellowstone		139,500		20,000	40,000	10,000							
Missouri River													
Thermal Electric	5	19,500							5,000				
	6	23,000								5,900			
	7	23,000										5,900	
	8	23,000										5,900	
	9	23,000									5,900		
	10	23,000							5,900				
	11	23,000										5,900	
Gasification	10	30,000								20,000			
	11	30,000								20,000			
	12	30,000								20,000			
	13	30,000								20,000			
	14	30,000								20,000			
	15	30,000							20,000				
	16	30,000							20,000				
Total Missouri		367,500							45,900	105,900	5,900	17,700	
Powder River													
Reservoir Evap.		42,600											
Gasification		30,000											20,000
Total Powder		72,600											20,000
Total		761,600		20,000	40,000	60,000	20,000	25,900	45,900	105,900	5,900	17,700	20,000

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Table 22

Summary of Flow and TDS Levels after Most Probable Development

Month	Flow Remaining (1,000 AF Units)						TDS Concentrations (ppm)					
	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck
Oct	148.4	434.3	22.8	14.6	449.4		670	483	726	1,559	535	
Nov	150.3	390.7	24.9	13.9	406.4		655	510	700	1,544	546	
Dec	137.0	320.9	19.2	13.4	324.2		638	557	777	1,559	594	
Jan	129.0	288.8	17.4	12.1	302.8		630	600	807	1,596	608	
Feb	131.0	300.4	18.9	13.3	333.2		594	561	793	1,360	559	
Mar	271.4	547.4	40.2	30.6	698.5		662	447	590	1,088	441	
Apr	246.2	523.8	35.7	24.4	626.1		635	446	616	1,206	457	
May	240.4	959.9	47.2	44.0	927.2		688	351	553	1,125	408	
June	249.8	1,876.1	90.6	69.7	1,955.8		618	174	449	1,022	327	
July	287.9	1,233.6	33.3	20.8	1,283.6		602	307	594	1,191	379	
Aug	123.6	453.2	12.6	9.4	429.7		557	508	835	1,397	530	
Sept	135.2	393.7	16.6	8.7	368.8		554	513	771	1,346	554	
	2,250.2	7,722.8	379.4	274.9	8,105.7	15,898.1	637	392	616	1,221	439	447

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Table 23

Summary of Diversions and Return Flows in 1,000 AF Units
Extensive Development, First Choice

	Plant No	Diversion 1,000 AF	RETURN FLOW				Powder River									Total Return Flows	Total Depletions
			Sarpy Creek	Armells Creek	Total Above Yellowstone River at Miles City	Tongue River	Above Moorhead	Below Moorhead	Total Above Yellowstone River at Sidney	Knife River	Main Stem Above Bismarck	Heart River	Cannonball River	Cheyenne River	Rosebud Creek		
Bighorn Powerplant	1	23,000						5,900									
	2	19,500				5,000											
	3	19,500				5,000											
	4	19,500				5,000											
Gasification plant	1	30,000												20,000			
	2	30,000												20,000			
	3	30,000						20,000									
	4	30,000						20,000									
	5	30,000						20,000									
	6	30,000						20,000									
	7	30,000					20,000										
	8	30,000					20,000										
	9	30,000					20,000										
	10	30,000				20,000											
	11	30,000				20,000											
	12	30,000				20,000											
	13	30,000	20,000														
	14	30,000	20,000														
	15	30,000	20,000														
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	17	30,000		20,000													
	18	30,000		20,000													
	19	30,000		20,000													
	20	30,000		20,000													
	21	30,000		20,000													
	22	30,000													20,000		
	23	30,000				20,000											
	24	30,000				20,000											
Total Bighorn		801,500	80,000	100,000	200,000	115,000	60,000	85,900	(460,900)	-	-	-	-	40,000	20,000	500,900	300,600
Missouri River Powerplants	5	19,500									5,000						
	6	23,000									5,900						
	7	23,000											5,900				
	8	23,000											5,900				
	9	23,000										5,900					
	10	23,000									5,900						
	11	23,000											5,900				
Gasification plant	25	30,000										20,000					
	26	30,000								20,000							
	27	30,000								20,000							
	28	30,000								20,000							
	29	30,000								20,000							
	30	30,000								20,000							
	31	30,000								20,000							
	32	30,000								20,000							
	33	30,000								20,000							
	34	30,000								20,000							
	35	30,000								20,000							
	36	30,000								20,000							
	37	30,000								20,000							
	38	30,000								20,000							
	39	30,000									20,000						
	40	30,000									20,000						
	41	30,000									20,000						
Total Missouri		667,500	-	-	-	-	-	-	-	260,000	76,800	25,900	17,700	-	-	380,400	287,100
Total		1,469,000	80,000	100,000	20,000	115,000	60,000	85,900	460,900	260,000	76,800	25,900	17,700	40,000	20,000	881,300	587,700

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Table 24

Summary of Flow and TDS Levels after Extensive Development

	Flow Remaining (1,000 AF Units)						TDS Concentrations (ppm)					
Month	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck	Bighorn at Bighorn	Yellowstone River at Miles City	Tongue River at Miles City	Powder River at Moorhead	Yellowstone River at Sidney	Missouri River at Bismarck
Oct	102.9	412.1	26.2	16.2	443.8		665	500	777	1,331	549	
Nov	114.1	377.8	28.2	16.9	411.5		690	533	746	1,324	578	
Dec	107.1	314.3	22.6	15.2	334.4		572	598	807	1,338	570	
Jan	103.3	286.4	20.7	13.6	316.9		599	655	824	1,324	623	
Feb	101.8	294.5	22.3	18.7	347.7		638	601	835	1,315	616	
Mar	139.4	438.7	43.5	45.7	620.0		669	457	638	1,182	447	
Apr	118.0	418.9	39.1	37.8	549.6		743	456	669	1,211	465	
May	143.0	885.8	50.5	65.5	889.7		715	351	609	1,115	421	
June	327.2	1,976.8	94.0	92.7	2,094.6		638	250	488	1,049	360	
July	198.4	1,167.4	36.6	32.5	1,244.2		615	307	649	1,226	387	
Aug	84.6	437.5	16.0	14.4	434.7		629	537	813	1,278	567	
Sept	91.2	373.0	19.9	12.6	367.0		586	546	772	1,278	590	
	1,631.0	7,383.2	419.6	381.8	8,053.4	15,650.7	647	387	662	1,182	459	479

Table 25

Water Quality Impact Summary

Bighorn River at Bighorn

Water Quality in TDS (Units ppm)

Month	Adjusted 1970 Level	Base Level Devel.	Most Probable Devel.	Extensive Development
Oct	667	667	670	665
Nov	652	652	655	690
Dec	635	635	638	592
Jan	627	627	630	599
Feb	599	599	594	638
Mar	661	661	662	669
Apr	693	693	635	743
May	687	687	688	715
June	620	620	618	638
July	601	601	602	615
Aug	551	551	557	629
Sept	551	551	554	586
Average	634	634	637	647

impacts for this scenario would vary above adjusted 1970 levels by a maximum of 6 ppm in August and show a reduction of TDS in the month of April of 58 ppm. Under the Extension Development Scenario TDS levels would increase 13 ppm above adjusted 1970 level on an average annual basis. Maximum monthly impacts on adjusted 1970 levels would vary from a 108 ppm increase in April (635 ppm to 743 ppm) to a decrease of 66 ppm in April. Table 25 is a summary of the effects of coal development.

Yellowstone River at Miles City.--The water quality, as measured by TDS, for the Yellowstone River at Miles City will improve slightly from adjusted 1970 levels as a result of coal development. There are no depletions of either water or salt as a result of Base Development. Therefore, flow and quality remain unchanged from adjusted 1970 levels. The developments assumed for the other scenarios have only a slight impact, reducing TDS concentrations 4 ppm and 9 ppm respectively for Most Probable and Extensive Developments. Table 26 is a summary of the water quality impacts on the Yellowstone River at Miles City.

Tongue River at Miles City.--The water quality of the Tongue River at Miles City will be adversely affected by each of the three scenarios.

Base Level Development would increase TDS levels on an average annual basis from 496 ppm to 609, an increase of 23 percent. All but the month of February will be adversely affected with the maximum effect felt in September when TDS concentrations will be increased from 620 ppm to 832 ppm.

The Most Probable Development on the Tongue River will increase TDS concentrations approximately 24 percent in the average year. The worst months are during the late fall and winter from October through February. February would be affected most with an increase of 208 ppm, from 585 ppm at 1970 levels to 793 ppm after development.

Extensive Level Developments would increase TDS concentrations 33 percent above 1970 levels, which is the most severe impact on any stream for any scenario.

Table 27 is a summary of these impacts.

Powder River at Moorhead.--The quality of water of the Powder River at Moorhead would be degraded somewhat under Base Level Development, would remain relatively unchanged for Most Probable Development, and would be slightly improved under Extensive Development conditions.

Average annual TDS concentrations for Base Development would increase about 15 percent from 1970 levels. The worst month would be August with a TDS increase of 1,380 ppm from 1,550 to 2,930 ppm; although, all months are adversely affected.

Most Probable conditions indicate a 1,221 ppm TDS level at Moorhead, down from 1,226 under 1970 level conditions on an average annual basis. Fall and early winter months show some degradation particularly November then an increase from 1,480 to 1,544 ppm would be recorded. Seven of the 12 months would show a decrease in TDS levels.

Under Extensive Development, TDS concentrations would be reduced in every month from 1970 level conditions with an average annual reduction of about 4 percent, from 1,226 ppm to 1,182 ppm. Table 28 is a summary of these data.

Yellowstone River at Sidney.--The quality of the Yellowstone River at Sidney as measured by TDS would be little changed by coal development.

Base Development would cause less than a 2 percent increase in TDS (444 ppm under 1970 level conditions to 451 ppm). Every month of the year shows an increase in TDS levels ranging from 3 to 33 ppm.

The average annual TDS concentration would reduce from 444 ppm (1970 level) to 439 under Most Probable conditions. Individual months varied from an increase of 18 ppm to a reduction of 17 ppm.

Under Extensive Development conditions all but 4 months would show an increase in TDS from 1970 levels. On an average annual basis, TDS levels would increase 15 ppm (from 444 ppm under 1970 level conditions to 459 ppm). Table 29 is a summary of the results.

Missouri River at Bismarck.--Water quality deterioration as measured by an increase in TDS for the Missouri River at Bismarck is shown in the following tabulation:

Missouri River at Bismarck

1970 Level Conditions	Base Level Devel.	Most Probable Devel.	Extensive Development
441	444	447	454

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Table 26

Water Quality Impact Summary

Yellowstone River at Miles City

Water Quality in TDS (Units ppm)

Month	Adjusted 1970 Level	Base Level Devel.	Most Probable Devel.	Extensive Development
Oct	500	500	483	477
Nov	510	510	510	521
Dec	570	570	557	541
Jan	595	595	600	598
Feb	560	560	561	590
Mar	450	450	447	401
Apr	450	450	446	402
May	355	355	351	329
June	255	255	174	276
July	310	310	307	295
Aug	505	505	508	524
Sept	510	510	513	524
Average	396	396	392	387

Table 27

Water Quality Impact Summary

Tongue River at Miles City

Water Quality in TDS (Units ppm)

Month	Adjusted 1970 Level	Base Level Devel.	Most Probable Devel.	Extensive Development
Oct	560	682	726	777
Nov	545	688	700	746
Dec	590	694	777	807
Jan	605	788	807	824
Feb	585	577	793	835
Mar	490	615	590	638
Apr	500	585	616	669
May	470	561	553	609
June	410	499	449	488
July	510	568	594	649
Aug	680	755	835	813
Sept	620	832	771	772
Average	496	609	616	662

Table 28

Water Quality Impact Summary

Powder River at Moorhead

Water Quality in TDS (Units ppm)

Month	1970 Level	Base Level Devel.	Most Probable Devel.	Extensive Development
Oct	1,510	2,470	1,559	1,331
Nov	1,480	1,760	1,544	1,324
Dec	1,540	1,760	1,559	1,338
Jan	1,570	1,810	1,596	1,324
Feb	1,430	1,600	1,360	1,315
Mar	1,200	1,260	1,088	1,182
Apr	1,240	1,333	1,206	1,211
May	1,120	1,210	1,125	1,115
June	1,050	1,130	1,022	1,049
July	1,290	2,150	1,191	1,226
Aug	1,550	2,930	1,397	1,278
Sept	1,600	2,100	1,346	1,278
Average	1,226	1,404	1,221	1,182

Table 29

Water Quality Impact Summary

Yellowstone River at Sidney, Montana

Water Quality in TDS (Units ppm)

Month	Adjusted 1970 Level	Base Level Devel.	Most Probable Devel.	Extensive Development
Oct	524	538	535	549
Nov	537	548	546	578
Dec	579	590	594	570
Jan	590	606	608	623
Feb	560	564	559	616
Mar	458	461	441	447
Apr	470	473	457	465
May	421	424	408	421
June	336	337	327	360
July	386	392	379	387
Aug	528	538	530	567
Sept	550	583	554	590
Average	444	451	439	459

Dissolved Oxygen

Large population increase in the study area resulting from coal developments could cause oxygen deficiencies in waste collecting streams if the assimulative capacity of the stream is exceeded.

Three locations were selected and analyzed to determine if dissolved oxygen problems would occur. The communities evaluated were Billings and Miles City, Montana, on the Yellowstone River and Sheridan, Wyoming, in the Tongue River Basin.

The dissolved oxygen demand at Billings was estimated to be 17 mg/l resulting from a 22 MGD discharge. The mean water temperature for August was assumed to be 22°C resulting in a dissolved oxygen (DO) concentration of 7.8 mg/l at future critical levels of flow prior to discharge. The calculation indicates the treated waste load is very much within the assimulated capacity of the river. The proposed Montana State standard at this location is 5.0 mg/l.

Yellowstone River at Miles City, Montana.--The Yellowstone River at Miles City is assumed to be flow impacted by Northern Great Plains coal-energy development. Therefore, the DO analysis will be performed using the Instream Needs Flows. The Instream Needs Flow for the Yellowstone at Miles City is 5,100 cfs for August. Assume, for the moment, a population of 25,000 for the year 2000. Under the assumptions stated for this analysis, this population would create an effluent discharge of approximately 5 cfs resulting in an ultimate oxygen demand of 0.13 mg/l after mixing with the river. At this point it is obvious that there is no need to continue the analysis, since such a low ultimate demand could not significantly deplete the dissolved oxygen concentration. Therefore, with secondary treatment as defined for this analysis, the DO concentration in the Yellowstone should not be substantially changed as a result of this Miles City effluent. This analysis assumes complete mixing, therefore does not address possible local DO problems resulting from poor mixing.

Goose Creek at Sheridan, Wyoming.--Goose Creek is a tributary of the Tongue River and is located near the headwaters of the River. Sheridan, Wyoming, with a 1970 population of 10,856, discharges its municipal wastes into Goose Creek. This stream is not expected to be flow impacted by coal-energy development, and consequently the 7-day, 10-year low flow of 11 cfs will be used for analysis. A population of 10,000 is estimated to discharge treated wastes at a rate of 2 cfs. This discharge, after secondary treatment and mixing with the stream, would result in an ultimate oxygen demand of 18 mg/l. The mean water temperature of Goose Creek at Sheridan is estimated to be 22°C during August, resulting in a DO saturation concentration of 7.5 mg/l after correction for elevation. The Wyoming dissolved oxygen standard for this tributary of the Tongue River is 6.0 mg/l. Assuming an average stream depth of 0.8 feet and an average velocity of 1 foot-per-second, the critical DO deficit is calculated to be 0.8 mg/l at 2.5 miles downstream of the discharge. This deficit would result in a DO concentration at this downstream point of 6.7 mg/l, which indicates that the present population, even with secondary treatment, can significantly deplete the dissolved oxygen concentration. If "background" oxygen demands are present to cause an additional 0.5 mg/l deficit, the critical DO concentration would be 6.5 mg/l, very near the State standard.

To determine the dissolved oxygen impact of population growth in Sheridan due to coal-energy development, an analysis is performed initially assuming a population of 20,000. The results indicate that for secondary treatment and the assumed stream conditions a population between 14,000 and 23,000 would cause the DO concentration in Goose Creek to drop to the State standard of 6.0 mg/l. While these results represent a substantial range in population, they can be compared with population projections to obtain information on whether a problem may result from coal-related growth.

Effects of Mining on Ground Water

Ground-water conditions and possible effects of strip mining on shallow aquifers were evaluated for the Gillette area of Wyoming, Birney-Decker area of Montana, and Gascoyne area (Western Williston Basin) in North Dakota.

Strip mining will usually interrupt several aquifers. Detailed investigation of each mining site and mining plan would be needed to determine which aquifers might be cut and how far the effects may extend.

Most mining will tap alluviums or bedrock, also recharge or discharge areas. In all cases water levels in wells and springs are expected to be lowered. Those mining cuts which tap bedrock will require special precautions to prevent poor quality water from leaking into underlying aquifers. Those which tap ground water discharge areas might have local quality problems which can be contained within the mining area. Mining cuts which tap the alluviums could perhaps cause degradation of both quantity and quality of ground water. Essentially all mining sites will be in recharge areas where problems are expected to be less serious.

Prevention and correction of most quality problems can be effected if hydrologic conditions are determined in the predevelopment stage; then, development plans and mining activities can take advantage of the natural flow system to avoid damaging the ground-water resource.

Ground-water levels will be lowered within an area of influence of a mining excavation. Normally, the water table adjacent to the cut will be lowered to the elevation of the mine floor. This could be in the 200 to 300 foot range. Distance from the cut will measure the extent of water level decline, and in most cases the effect will not be noticeable beyond a mile. The influence may be up to 3 or 4 miles, however, in some locations.

During the period from interruption to reclaiming of a mine, wells within the area of influence will need to be replaced, usually by drilling to an underlying aquifer. This may be up to 500 feet deeper in some locations to insure complete replacement. Usually the water from deeper aquifers will be of equivalent quality to that of the interrupted supply, but may be either better or worse. In the Gillette area, the deeper water will be softer and contain less dissolved solids than in the coal and shallow aquifers overlying the coal. In the Decker area, replacement water will be of equivalent quality unless existing supply is from a clinker bed which possesses the best available quality in the area and any replacement supply would be inferior. The Gascoyne area replacement water can be selective; the Ludlow formation would provide equivalent quality but deeper aquifers would yield better water. The period between interruption and complete restoration is expected to be from 10 to 15 years, or perhaps longer in some cases, and replacement supplies will be required during that time.

Upon completion of reclaiming mined areas, shallow ground waters are expected to return to essentially their original levels. This is especially true if rubble from waste coal and boulders at the base of the backfill is moderately permeable. If the base material in the backfill is relatively impermeable, water in nearby shallow wells should stand higher than predisturbed levels.

Quantities of ground water discharged at any particular mine will be generally small, from 0.5 to 2.0 cfs. These amounts of water are not difficult to manage, and possible utilization or proper disposal can be planned depending on its quality and relationship to surrounding conditions. Only along Otter Creek in the Knobloch coal bed would mining be expected to produce significant amounts of water, and even there the quantity would be expected to be less than 5 cfs.

Water quality changes from leachates is more speculative. Percolation of rainfall through the unconsolidated spoil bank material is expected to make wider contact with the minerals present and concentrate most of the chemical constituents. How much degradation in quality can be expected is currently beyond answer. An attempt is underway to study this facet, but observations have not been accomplished as yet. If leachates contain high concentrations of objectionable trace elements or metals, it may be desirable to plan a collection system for disposal through evaporation processes.

More detailed information on the ground-water impacts of mining is contained in the Report on Shallow Ground Water by the Ground Water Subgroup.

FINDINGS

Disorganization

Individual energy companies have recently taken, and are currently taking, actions which will lead to fragmented energy development and to conflicts with other water needs. The actions are complicating State and county government operations and creating confusion within local interest groups and among individual citizens in each of the coal States. Concurrently, companies are frustrated by the inability of others to arrive at conclusions which would permit them to proceed with development.

To insure the availability of water for their purposes companies have filed water rights, applied for storage sites, purchased irrigated lands for the water supply, and undertaken a variety of costly technical studies.

State authorities are having to make decisions without adequate data. Legislative bodies are passing bills which complicate planning, and law suits are being filed regarding surface and ground-water proposals. Farmers, ranchers, and irrigation districts have not been able to learn the needs of industry for water and lack understanding of probable impacts.

Environmental organizations are taking steps (EDF vs. Morton [Civil 1220, U.S. Dist. Ct., Mont.] as an example) to insure their interests are protected. This results in delaying the decision-making processes and prevents or delays energy development. Federal Government officials have delayed making some decisions because of a lack of a national energy program, problems associated with mineral leasing, indecision on water marketing, and quantification of Indian water entitlements.

Constraints

Constraints to development of water resources for industrial use are numerous. Besides the inherent constraints of economics and engineering feasibility, there are also legal, institutional, social, cultural, aesthetic, and environmental constraints. Some of the more important specific ones may be the Yellowstone River Compact, Indian water needs and rights, future instream flow requirements, and aesthetic, cultural, and environmental values associated with free-flowing streams. Such constraints will play an important part in determining the type, location, extent and timing of water resource development.

Water Supply

Ground Water

Deep ground water may have substantial potential for use in coal conversion. Although the ground water is generally of poorer quality than the surface water, recovering it and treating it for use may be cheaper for some areas than transporting surface water, if the ground water is available in sufficient quantity. Impacts associated with development of ground water may be depletion or mining of that resource if withdrawal is greater than recharge, and possible effects on existing wells. Also, the discharge, if any, from coal conversion plants using ground water will probably be of poorer quality than if the plants used surface water. Separate and apart from the use of ground water in coal conversion, the strip mining of coal may have significant local effects on the quality and quantity of shallow ground water and require special management to avoid problems.

Surface Water

Surface water appears to be available in sufficient quantity to meet the medium range energy needs and probably more. Projected future uses of water above Sioux City for all purposes indicate that up to 3 million acre-feet annually could be utilized for industry without serious conflict. Of this, the Yellowstone Basin could provide annually certain amounts of water for all future uses, such as:

a. Up to 484,000 acre-feet with no new storage and satisfying suggested instream flows.

b. Up to 1,220,000 acre-feet with no new storage but not meeting suggested instream flows.

c. Up to 2,000,000 acre-feet with sufficient new storage and saitsfying suggested instream flows.

d. Up to 3,000,000 acre-feet with sufficient new storage but not meeting suggested instream flows.

Any of the water quantities listed would be reduced for industrial availability by the amounts depleted for future agricultural and municipal uses.

The primary impacts of providing surface water would be those normally associated with reservoirs where new storage is required and those impacts which accompany construction and operation of buried aqueducts. Water quality can, for the most part, be satisfactorily controlled to State standards, although costs may rise.

Caution

Fishery biologists and environmentalists may be relying on suggested instream flows to preserve the existing aquatic resources. There are some weaknesses, and further explanation seems appropriate.

First, the flow rates now suggested need much more study; values may be adjusted either upward, downward, or seasonally.

Second, Montana streams named in the Yellowstone River Compact, and the Yellowstone River itself from Laurel to Sidney, have suggested flow rates which include waters to which Wyoming is legally entitled. Of the 8.8 million acre-feet of water which now discharges into North Dakota from the Yellowstone in an average year, about 3 million acre-feet could be diverted by Wyoming and not be available to Montana.

Third, on almost all tributary streams within the Yellowstone Basin, there is an overappropriation of water by prior water right holders. Thus, in any normal year, the appropriators can, and do, legally dry up many streams. The Yellowstone proper has not been overappropriated, but Wyoming's tributary entitlements, if they had been diverted, would have resulted in the Yellowstone becoming dry on many occasions historically.

Fourth, Wyoming and some of the work group members do not agree that some streams, for example Powder River, possess aquatic values which warrant preservation at the expense of other considerations.

Fifth, federally constructed storage on the Bighorn River has water rights which predate the Montana Water Use Act of 1973. Disposition of its water would probably not be subordinate to streamflow preservation, and may not be available to meet suggested instream flows.

Recommendations

If it is decided that the Northern Great Plains coal will be used to supply certain national energy needs, water will be a primary factor. So that usable information will be available in time, we believe that immediate investigations should be undertaken regarding water supply and delivery costs. Therefore, we recommend that:

1. A ground-water exploration program be initiated concerning the Madison and underlying formations to determine whether deep ground water can be recovered, well-drilling costs,

probable yields, recharge, drawdown and spacing requirements, and overall potential and life of this predicted resource; and concurrently

2. A feasibility-level surface water investigation be undertaken to supply answers regarding amounts and locations of new storage where required, aqueduct routing, delivery cost of water, water quality analyses, impacts, alternatives, and environmental assessment; and

3. A study of the specific demands for water and the technological alternatives that might be used to reduce such demand.

APPENDIXES

Scenario Water Supply

Water Availability

Instream Needs

Wild and Scenic Rivers - Recreation

SCENARIO WATER SUPPLY APPENDIX

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Note: Plates referred to in this appendix are plates of the main report (in the manila envelope).

SCENARIO WATER SUPPLY APPENDIX
Work Group (C) Water
Northern Great Plains Resource Program

Purpose

This appendix summarizes the activities related to derivation of costs of storage and water transmission facilities of the Northern Great Plains Resource Program. The work was delegated to several subgroups to make refined locations, size of the facilities, and estimate cost of water delivered to potential mine-mouth steam electric generating plants and gasification plants in the three States of North Dakota, Montana, and Wyoming. The costs were compiled over a period of 15 months and many sources were used, especially for the storage dams.

Geographical Scope

The study of water storage and conveyance facilities is broad in geographical scope. It encompasses plans for delivery of water to coal fields in Montana, North Dakota, and Wyoming. The water conveyance systems for the alternative layouts to serve a plant or group of plants varies from a minimum of 3 miles to serve P-6 from the Missouri River to a maximum of 214 miles to serve the group of plants south of Gillette in Alternative 3 - Gillette area transposed.

Functional Scope

The study deals only with facilities needed to store and deliver the required quantity of water to potential steam electric generating plants and gasification plants. It was assumed that water would be delivered in harmony with existing water rights, water laws, and with least disturbance of the natural environment as required by the National Environmental Act of 1969 (P.L. 91-190), as amended.

Technical

Many and varied technical problems of hydraulic and structural design will probably be encountered by subsequent investigators and designers. However, the work group did not consider any problems insurmountable insofar as constructing facilities to deliver the required amount of water is concerned. The quantity of water for gasification plants was recommended by the Minerals

Work Group. Quantities needed for generating plants were derived from data supplied by the Montana Power Company. Annual water deliveries are listed in each of the tables for each forecast and for each choice and alternative.

Level of Technology

The plans and estimates of cost are based on January 1973 level of technology for construction and materials of construction.

Maps and Surveys

The route studies of water conveyance facilities consisted generally of layouts on 7½-minute quandrangle maps, scale 1:24,000, which are published by the United States Geological Survey. Approximately one-third of the layouts were made from Army maps, scale 1:250,000. Layouts and sitings were made as realistically as possible, although no field surveys were made of any site or route for the study except for those aqueducts that followed the same general alignment as studied under the Montana-Wyoming Aqueduct Investigation. Some field information is available such as reconnaissance geology on the alignments. Water conveyance routes and plant locations are shown on Plates 5 through 14. In general, the right-of-way take was assumed to be 200 feet wide for estimating purposes. Actual right-of-way requirements may be less than this width. Access roads were included wherever necessary to insure site accessibility.

Hydraulic Assumptions

The pipelines, pumping plants, flow-control structures, and other appurtenant facilities were sized to deliver the annual water requirements within 350 days. The pipelines were sized using Scoby's coefficient of roughness equal to 0.37 and $n = 0.013$ of the Manning Formula for tunnels. Each delivery plan included a terminal storage pond capable of meeting a 3-day demand at each delivery point. Each pond could be refilled during off-peak operations. Reuse of water was not considered because it was assumed that reuse was already accounted for in the requirement for each site. Dispostion of mineral effluents was assumed to be a part of plant costs and not a water delivery cost.

The number of pumping lifts was determined from the total dynamic lift between diversion point and plant site. Pump lifts were limited to about 250 feet total dynamic head (TDH) maximum where possible. Flow-control structures were used wherever gravity flow was present in a portion of the line. They were used on gravity portions of the lines with a maximum static drop of 150 feet between stations at each 150-foot drop in elevation along the line. Hydraulic head loss was assumed but not computed for inlet channels, chlorination stations, valves, terminal storage, etc. Control buildings and telemetry equipment would be included as part of the operating facilities of the conduit.

Structural Design Assumptions

The costs were based on average foundation conditions at all structure sites and conduit routes, and it was assumed that any foundation deficiency could be overcome without abnormal costs involved. The structural and operational safety of the facilities would be guaranteed against overloading by use of forebays, surge tanks, air valves, accessory mechanical and electrical equipment, etc. No new geological studies were undertaken for the preparation of plans and cost.

Method of Cost Estimation

Pipeline sizing was based on studies of economical size pipe for various flows, hydraulic head, and structural safety. After sizing studies of pipelines were completed for various flows, pipe costs were determined for each pipe head class increment (50 feet). Pipeline costs were then determined from cost curves which included earthwork, furnishing and laying pipe, allowance for breakage, etc. An adequate allowance was included to cover contingencies, horizontal and vertical blocking, blowoff valves, air inlet and release valves, and highway and stream crossings. Costs of complete pumping plants (except electrical transmission lines), flow-control structures and attendant regulating tanks, inlet channels, chlorination stations, and terminal storage were estimated from cost curves developed for other but similar studies. An allowance of 2 percent of identifiable costs was included for landscaping and environmental enhancement. Land acquisition costs for right-of-way was based on $75 to $125 per acre. Access roads, where necessary, averaged about $20,000 per mile.

Indirect costs such as costs for engineering studies, surveys, designs, specifications, exploration, testing, inspection, administration, etc., were estimated on a percentage of field costs, generally about 20 percent, depending on the magnitude and expected complexity of each plan. All costs are based on the January 1973 price index of construction costs.

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Acquisition of Water Rights

The right to use water will be inherent in the purchase of water from a storage facility. Cost of making water available is shown as a separate cost item in the tabulations of costs under the heading of basic water charge. Water Cost from the Bighorn River or Yellowstone River is shown as $9 per acre-foot and was assumed to be storage water released from Bighorn Lake.

Water from Fort Peck, Lake Sakakawea and Lake Oahe has been shown herein to cost $9 per acre-foot; the same cost was assumed for water diverted from the Missouri River downstream from a main-stem storage facility. The actual price of water from main-stem reservoirs is under study and might be considerably different than used in this report. Water from potential new reservoirs such as Pumpkin, Arvada, Moorhead, New Tongue, Little Bighorn, Box Elder, Flatwillow and Mott would cost considerably more, depending on costs allocated to water conservation. The unit costs of water from these reservoirs as estimated for this study are tabulated in Table A-1. Interest used on new reservoirs indicate Federal financing under the 1958 Water Supply Act provisions.

Base Forecast

The unit costs of water to each plant site, based on January 1973 prices, under the two choices of the Base Forecast scenario are shown on Tables A-2 and A-3. These are total costs on a unit basis and include all field costs and costs for engineering, inspection, investigation, administration, overhead, replacement, and erergy plus interest at 8 percent to amortize the investment over 40 years of time. Under this scenario 124,000 acre-feet of water would be delivered to six steam-electric generating plants. Choice 2 is without additional storage reservoirs. The locations of the carriage facilities and plant sites are shown on Plates 5 and 6.

Most Probable Forecast

Under this scenario about 730,000 acre-feet of water would be delivered to 11 potential steam-electric generating plants and 16 gasification plants. The potential routes of aqueducts, plant sites and reservoir sites are shown on Plates 7 and 8. Under Choice 1, Pumpkin Reservoir is the one potential additional reservoir needed, but Choice 2 includes Moorhead, Flatwillow, Mott, and Box Elder reservoirs. The unit cost of water delivered to these 27 plant sites is tabulated on Tables A-4 and A-5.

Table A-1

Water Costs at Potential Reservoirs
Northern Great Plains Resource Program
Work Group (C) Water

Reservoir		Cost 1973 ($1,000)	Investment: Total Capital ($1,000)	Investment: Annual 4.012% 50 Yrs. ($1,000)	Annual OM&R ($1,000)	Annual Yield AF	Water Charge $/AF
Flatwillow		$17,630					
	IDC	1,060	18,690	872	25	12,100	$74
Moorhead		58,200					
	IDC	4,670					
	Flood Control	-4,500	58,370	2,723	50	77,000	36
Box Elder		29,460					
	IDC	1,770					
	Flood Control	-17	31,213	1,456	25	34,000	44
New Tongue		42,750					
	IDC	3,430					
	Flood Control	-2,380	43,800	2,043	30	63,000	33
Pumpkin		62,600					
	IDC	5,020					
	Flood Control	-1,500	66,120	3,084	50	70,000	45
Kendall		26,150					
	IDC	1,570					
	Flood Control	-700	27,020	1,260	25	85,000	15 1/
Mott		21,980					
	IDC	1,320					
	Flood Control	-1,000	22,300	1,040	25	13,000	82
Arvada		72,400					
	IDC	5,810					
	Flood Control	-1,700	76,510	3,569	50	65,000	56
Little Bighorn		27,950					
	IDC	1,680					
	Flood Control	-170	29,460	1,374	25	40,000	35
Lower Green		31,963	38,856	1,741	100	450,000	4
	IDC	3,206					

Flood control allocation based on capitalized benefits (5-5/8%).

Amortization of investment 4.012% over 50 years.

1/ Water delivered via Pathfinder Reservoir from Kendall Reservoir = $54.10 indexed to January, $73(\frac{1.41}{1.15})$ = $66.33/A.F. X 186% (change of Int. rate) = $123.30/A.F.

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Table A-2
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Base Forecast - Choice 1

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 73)
Powder River-Moorhead Reservoir	P-1	23,000	$115.00
New Tongue Reservoir	P-2	19,500	74.00
New Tongue Reservoir	P-3	19,500	84.00
New Tongue Reservoir	P-4	19,500	48.00
Fort Peck Lake	P-5	19,500	79.00
Missouri River Downstream of Lake Sakakawea	P-6	23,000	38.00

Table A-3
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Base Forecast - Choice 2

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 73)
Bighorn River at Hardin	P-1	23,000	$325.00
Bighorn River at Hardin	P-2	19,500	193.00
Bighorn River at Hardin	P-3	19,500	210.00
Bighorn River at Hardin	P-4	19,500	257.00
Flatwillow	P-5	19,500	299.00
Missouri River Downstream of Lake Sakakawea	P-6	23,000	38.00

Table A-4
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Most Probable Forecast - Choice 1

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 73)
Bighorn River at Hardin	P-1	23,000	$230.00
Bighorn River at Hardin	P-2	19,500	144.00
Bighorn River at Hardin	P-3	19,500	165.00
Yellowstone River	P-4	19,500	167.00
Fort Peck	P-5	19,500	80.00
Lake Sakakawea	P-6	23,000	89.00
Lake Sakakawea	P-7	23,000	222.00
Lake Sakakawea	P-8	23,000	175.00
Lake Sakakawea	P-9	23,000	102.00
Lake Sakakawea	P-10	23,000	140.00
Lake Sakakawea	P-11	23,000	198.00
Powder River-Pumpkin Reservoir	G-1	30,000	176.00
Bighorn River at Hardin	G-2	30,000	310.00
Bighorn River at Hardin	G-3	30,000	210.00
Bighorn River at Hardin	G-4	30,000	118.00
Bighorn River at Hardin	G-5	30,000	93.00
Yellowstone River	G-6	30,000	124.00
Yellowstone River	G-7	30,000	74.00
Yellowstone River	G-8	30,000	47.00
Yellowstone River	G-9	30,000	151.00
Lake Sakakawea	G-10	30,000	50.00
Lake Sakakawea	G-11	30,000	50.00
Lake Sakakawea	G-12	30,000	50.00
Lake Sakakawea	G-13	30,000	53.00
Lake Sakakawea	G-14	30,000	47.00
Lake Sakakawea	G-15	30,000	35.00
Lake Sakakawea	G-16	30,000	30.00

Table A-5
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Most Probable Forecast - Choice 2

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 73)
Powder River-Moorhead Reservoir	P-1	23,000	$ 90.00
Yellowstone River	P-2	19,500	181.00
Yellowstone River	P-3	19,500	160.00
Yellowstone River	P-4	19,500	119.00
Flatwillow Reservoir	P-5	19,500	296.00
Lake Sakakawea	P-6	23,000	54.00
Cannonball River-Mott Reservoir	P-7	23,000	95.00
Cannonball River-Mott Reservoir	P-8	23,000	124.00
Lake Sakakawea	P-9	23,000	152.00
Lake Sakakawea	P-10	23,000	104.00
Cannonball River-Mott Reservoir	P-11	23,000	216.00
Powder River-Moorhead Reservoir	G-1	30,000	275.00
Powder River-Moorhead Reservoir	G-2	30,000	134.00
Box Elder Reservoir	G-3	30,000	66.00
Yellowstone River	G-4	30,000	197.00
Yellowstone River	G-5	30,000	266.00
Yellowstone River	G-6	30,000	126.00
Yellowstone River	G-7	30,000	67.00
Yellowstone River	G-8	30,000	43.00
Yellowstone River	G-9	30,000	131.00
Lake Sakakawea	G-10	30,000	52.00
Lake Sakakawea	G-11	30,000	52.00
Lake Sakakawea	G-12	30,000	52.00
Lake Sakakawea	G-13	30,000	79.00
Lake Sakakawea	G-14	30,000	88.00
Lake Sakakawea	G-15	30,000	28.00
Lake Sakakawea	G-16	30,000	26.00

Extensive Development

Under this scenario about 1,500,000 acre-feet of water would be conveyed through about 600 miles of aqueducts to deliver water to 11 steam-electric generating plants and 42 gasification plants. Under this level of development three choices of aqueducts were considered with an additional four alternatives to serve some of the potential plants. Under Choice 1 no new storage would be needed to supply water. Accordingly all costs are for potential diversions and carriage facilities to the plant sites plus $9 per acre-foot for storage costs from the existing reservoirs. Table A-6 is a summary of unit costs of water to each plant under this choice and the layout is shown on Plate 9.

The layout scheme for Choice 2 also would receive all water from existing reservoirs except plant G-1. Green River water from the potential Kendall Reservoir was the assumed source of water for this plant. Water could be delivered from Kendall Reservoir through a carriage system into existing Pathfinder Reservoir, then released to the North Platte River for diversion near Douglas, Wyoming, to G-1. The cost of water at the point of diversion from North Platte was estimated to cost $66 per acre-foot which appears competitive with water from the Yellowstone Basin. Table A-7 contains a summary of unit costs of water delivered to each plant. Plate 10 shows the aqueduct routes.

Choice 3 is another plan of water service to plants in southern Montana and northern Wyoming. It requires the construction of Arvada Reservoir on the Powder River and Little Bighorn Reservoir on the Little Bighorn River. Potential plant G-1 is assumed to be supplied from a system of ten ground-water wells, 12,000-feet deep along a 5-mile line near G-1. While technology exists to drill deep wells, the capability to obtain and deliver 2,000 gpm at each well is unproven and untested and should be viewed with skepticism at this time. The estimated cost of $45 per acre-foot appears more favorable than the import of surface water, but cost of treatment to correct chemical quality deficiencies may show surface water to be preferable   Table A-8 is a summary of costs under this plan of delivery, and Plate 14 shows the layout.

Alternative 3 - North Dakota is a plan for a single diversion of the entire amount of water from Lake Sakakawea to serve 678,000 acre-feet to the 24 potential plants in North Dakota and the

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Table A-6

COST SUMMARY AND QUANTITY

Water Transmission and Storage at Plants

Extensive Development - Choice 1

Northern Great Plains Resource Program

Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 1973)
Big Horn River at Hardin	P-1	23,000	189.00
Big Horn River at Hardin	P-2	19,500	146.00
Big Horn River at Hardin	P-3	19,500	168.00
Big Horn River at Hardin	P-4	19,500	179.00
Fort Peck Lake	P-5	19,500	80.00
Lake Sakakawea	P-6	23,000	64.00
Lake Sakakawea	P-7	23,000	199.00
Lake Sakakawea	P-8	23,000	152.00
Lake Sakakawea	P-9	23,000	95.00
Lake Sakakawea	P-10	23,000	116.00
Lake Sakakawea	P-11	23,000	182.00
Big Horn River at Hardin	G-1	30,000	378.00
Big Horn River at Hardin	G-2	30,000	268.00
Big Horn River at Hardin	G-3	30,000	238.00
Big Horn River at Hardin	G-4	30,000	225.00
Big Horn River at Hardin	G-5	30,000	207.00
Big Horn River at Hardin	G-6	30,000	207.00
Big Horn River at Hardin	G-7	30,000	195.00
Big Horn River at Hardin	G-8	30,000	189.00
Big Horn River at Hardin	G-9	30,000	161.00
Big Horn River at Hardin	G-10	30,000	133.00
Big Horn River at Hardin	G-11	30,000	133.00
Big Horn River at Hardin	G-12	30,000	92.00
Big Horn River at Hardin	G-13	30,000	47.00
Big Horn River at Hardin	G-14	30,000	47.00
Big Horn River at Hardin	G-15	30,000	47.00
Big Horn River at Hardin	G-16	30,000	47.00
Big Horn River at Hardin	G-17	30,000	118.00
Big Horn River at Hardin	G-18	30,000	97.00
Big Horn River at Hardin	G-19	30,000	76.00
Big Horn River at Hardin	G-20	30,000	76.00
Big Horn River at Hardin	G-21	30,000	76.00
Big Horn River at Hardin	G-22	30,000	105.00
Big Horn River at Hardin	G-23	30,000	154.00
Big Horn River at Hardin	G-24	30,000	154.00
Lake Sakakawea	G-25	30,000	109.00
Lake Sakakawea	G-26	30,000	49.00
Lake Sakakawea	G-27	30,000	49.00
Lake Sakakawea	G-28	30,000	49.00
Lake Sakakawea	G-29	30,000	49.00
Lake Sakakawea	G-30	30,000	49.00

Table A-6(Continued)

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 1973)
Lake Sakakawea	G-31	30,000	49.00
Lake Sakakawea	G-32	30,000	49.00
Lake Sakakawea	G-33	30,000	49.00
Lake Sakakawea	G-34	30,000	49.00
Lake Sakakawea	G-35	30,000	40.00
Lake Sakakawea	G-36	30,000	40.00
Lake Sakakawea	G-37	30,000	51.00
Lake Sakakawea	G-38	30,000	54.00
Lake Sakakawea	G-39	30,000	80.00
Lake Sakakawea	G-40	30,000	80.00
Lake Sakakawea	G-41	30,000	80.00
Lake Sakakawea	G-42	30,000	135.00

Table A-7
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development - Choice 2

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 1973)
Yellowstone River near Armells Creek	P-1	23,000	234.00
Yellowstone River near Armells Creek	P-2	19,500	143.00
Yellowstone River near Armells Creek	P-3	19,500	127.00
Yellowstone River near Armells Creek	P-4	19,500	97.00
Fort Peck Lake	P-5	19,500	79.00
Missouri R. downstream of L. Sakakawea	P-6	23,000	26.00
Missouri R. downstream of L. Sakakawea	P-7	23,000	192.00
Missouri R. downstream of L. Sakakawea	P-8	23,000	144.00
Missouri R. downstream of L. Sakakawea	P-9	23,000	173.00
Missouri R. dosnstream of L. Sakakawea	P-10	23,000	78.00
Missouri R. downstream of L. Sakakawea	P-11	23,000	184.00
Green River via North Platte	G-1	30,000	203.00
Yellowstone River near Armells Creek	G-2	30,000	328.00
Yellowstone River near Armells Creek	G-3	30,000	290.00
Yellowstone River near Armells Creek	G-4	30,000	274.00
Yellowstone River near Armells Creek	G-5	30,000	253.00
Yellowstone River near Armells Creek	G-6	30,000	253.00
Yellowstone River near Armells Creek	G-7	30,000	277.00
Yellowstone River near Armells Creek	G-8	30,000	271.00
Yellowstone River near Armells Creek	G-9	30,000	243.00
Yellowstone River near Armells Creek	G-10	30,000	152.00
Yellowstone River near Armells Creek	G-11	30,000	152.00
Yellowstone River near Armells Creek	G-12	30,000	298.00
Yellowstone River near Armells Creek	G-13	30,000	84.00
Yellowstone River near Armells Creek	G-14	30,000	84.00
Yellowstone River near Armells Creek	G-15	30,000	84.00
Yellowstone River near Armells Creek	G-16	30,000	84.00
Yellowstone River near Armells Creek	G-17	30,000	88.00
Yellowstone River near Armells Creek	G-18	30,000	68.00
Yellowstone River near Armells Creek	G-19	30,000	47.00
Yellowstone River near Armells Creek	G-20	30,000	47.00
Yellowstone River near Armells Creek	G-21	30,000	47.00
Yellowstone River near Armells Creek	G-22	30,000	76.00
Yellowstone River near Armells Creek	G-23	30,000	95.00
Yellowstone River near Armells Creek	G-24	30,000	95.00
Missouri R. downstream of L. Sakakawea	G-25	30,000	133.00
Missouri R. downstream of L. Sakakawea	G-26	30,000	76.00

Table A-7 (Continued)

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 1973)
Missouri R. downstream of L. Sakakawea	G-27	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-28	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-29	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-30	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-31	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-32	30,000	76.00
Missouri R. downstream of L. Sakakawea	G-33	30,000	47.00
Missouri R. downstream of L. Sakakawea	G-34	30,000	47.00
Missouri R. downstream of L. Sakakawea	G-35	30,000	66.00
Missouri R. downstream of L. Sakakawea	G-36	30,000	66.00
Missouri R. downstream of L. Sakakawea	G-37	30,000	49.00
Missouri R. downstream of L. Sakakawea	G-38	30,000	29.00
Missouri R. downstream of L. Sakakawea	G-39	30,000	32.00
Missouri R. downstream of L. Sakakawea	G-40	30,000	32.00
Missouri R. downstream of L. Sakakawea	G-41	30,000	32.00
Missouri R. downstream of L. Sakakawea	G-42	30,000	128.00

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Table A-8
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development - Choice 3

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./hr.	Total Cost Per A.F. (Jan. 1973)
Yellowstone River near Miles City	P-1	23,000	$162.00
Yellowstone River near Miles City	P-2	19,500	169.00
Yellowstone River near Miles City	P-3	19,500	146.00
Yellowstone River near Miles City	P-4	19,500	108.00
Groundwater Wells	G-1	30,000	45.00
Yellowstone River near Miles City	G-2	30,000	256.00
Yellowstone River near Miles City	G-3	30,000	217.00
Yellowstone River near Miles City	G-4	30,000	201.00
Yellowstone River near Miles City	G-5	30,000	180.00
Yellowstone River near Miles City	G-6	30,000	180.00
Arvada Reservoir - Powder River	G-7	30,000	143.00
Arvada Reservoir - Powder River	G-8	30,000	109.00
Arvada Reservoir - Powder River	G-9	30,000	140.00
Yellowstone River near Miles City	G-10	30,000	183.00
Yellowstone River near Miles City	G-11	30,000	183.00
Little Bighorn Res.-L. Bighorn R.	G-12	30,000	113.00
Yellowstone River near Miles City	G-13	30,000	172.00
Yellowstone River near Miles City	G-14	30,000	172.00
Yellowstone River near Miles City	G-15	30,000	172.00
Yellowstone River near Miles City	G-16	30,000	172.00
Yellowstone River near Miles City	G-17	30,000	168.00
Yellowstone River near Miles City	G-18	30,000	146.00
Yellowstone River near Miles City	G-19	30,000	134.00
Yellowstone River near Miles City	G-20	30,000	134.00
Yellowstone River near Miles City	G-21	30,000	134.00
Yellowstone River near Miles City	G-22	30,000	135.00
Yellowstone River near Miles City	G-23	30,000	92.00
Yellowstone River near Miles City	G-24	30,000	92.00

expected 36,000 acre-feet of additional municipal water. It is an alternative to Choices 1 and 2 of the Extensive Development Scenario. Unit cost of water at each plant under this scheme is tabulated on Table A-9. Plate 11 shows the layout of the pipelines.

Alternative 3 - Yellowstone Basin is an alternative plan for delivery of water to meet the requirements of coal plant needs in each of the two States independently of the other State. It features a diversion from the Yellowstone River near Armells Creek with aqueducts to serve the 18 plants in southern Montana. The ten plants in northern Wyoming would be served by a pump diversion from the Bighorn Lake and a system of tunnels, hydro-power plants, and pipelines all located in Wyoming. The hydro-plants would generate power at the eastern slope of the Bighorn Mountains where the aqueduct would dissipate considerable hydraulic head to reach the Tongue River area. The cost of water under this delivery plan to each plant are listed on Table A-10. Plate 13 shows the route layout of this all-Wyoming and all-Montana system.

The delivery plan of Alternative 3 - Gillette Area Transposed was formulated because of Article X of the Yellowstone River Company. This plan features a direct diversion of 315,000 acre-feet from Lake Oahe, 214 miles in length to serve 293,000 acre-feet to ten new plant sites generally south of Gillette, Wyoming, and 23,000 acre-feet to new municipal water users. The cost of water to each plant site under this scheme would vary from $316 to $370 per acre-foot as shown on Table A-11. The aqueduct layout is shown on Plate 12.

Alternative 4 is a plan for diverting up to 300,000 acre-feet of water from the potential Lower Green Reservoir near Green River, Wyoming, to the Gillette Area Transposed. This potential reservoir of 280,000 acre-feet capacity when operated in conjunction with Fontenelle Reservoir can yield up to 450,000 acre-feet annually. Water could be conveyed by aqueduct from the reservoir downstream to about Interstate 80, thence, generally parallel with Interstate 80 terminating in Sugar Creek near Rawlings, a tributary of the North Platte River, about 32 miles by river upstream of the existing Seminoe Reservoir. The water would pass through Seminoe and Pathfinder Reservoirs to near Douglas where it would be diverted from the North Platte River into a 131-mile, 293,000 acre-foot capacity pipeline for delivery to the Gillette area. The 96-inch pipeline from Lower Green Reservoir to Sugar Creek would be 136 miles in length with a capital cost of $384,492,000, annual power cost of $7,720,000, and OM&R of $1,045,000. The unit cost

Table A- 9
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development - Alternative 3 - North Dakota

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered A.F./yr.	Total Cost Per A.F. (Jan. 1973)
Lake Sakakawea	P-6	23,000	61.00
Lake Sakakawea	P-7	23,000	200.00
Lake Sakakawea	P-8	23,000	151.00
Lake Sakakawea	P-9	23,000	94.00
Lake Sakakawea	P-10	23,000	114.00
Lake Sakakawea	P-11	23,000	184.00
Lake Sakakawea	G-25	30,000	110.00
Lake Sakakawea	G-26	30,000	49.00
Lake Sakakawea	G-27	30,000	49.00
Lake Sakakawea	G-28	30,000	49.00
Lake Sakakawea	G-29	30,000	49.00
Lake Sakakawea	G-30	30,000	49.00
Lake Sakakawea	G-31	30,000	49.00
Lake Sakakawea	G-32	30,000	49.00
Lake Sakakawea	G-33	30,000	50.00
Lake Sakakawea	G-34	30,000	50.00
Lake Sakakawea	G-35	30,000	40.00
Lake Sakakawea	G-36	30,000	40.00
Lake Sakakawea	G-37	30,000	51.00
Lake Sakakawea	G-38	30,000	53.00
Lake Sakakawea	G-39	30,000	79.00
Lake Sakakawea	G-40	30,000	79.00
Lake Sakakawea	G-41	30,000	79.00
Lake Sakakawea	G-42	30,000	136.00

Table A-10
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development - Alternative 3 - Yellowstone Basin

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered AF/yr	Total Cost Per AF (Jan. 1973)
All Wyoming Aqueduct from Bighorn Lake	P-1	23,000	260.00
Yellowstone River near Armells Creek	P-2	19,500	158.00
Yellowstone River near Armells Creek	P-3	19,500	139.00
Yellowstone River near Armells Creek	P-4	19,500	105.00
All Wyoming Aqueduct from Bighorn Lake	G-1	30,000	318.00
All Wyoming Aqueduct from Bighorn Lake	G-2	30,000	307.00
All Wyoming Aqueduct from Bighorn Lake	G-3	30,000	293.00
All Wyoming Aqueduct from Bighorn Lake	G-4	30,000	283.00
All Wyoming Aqueduct from Bighorn Lake	G-5	30,000	270.00
All Wyoming Aqueduct from Bighorn Lake	G-6	30,000	270.00
All Wyoming Aqueduct from Bighorn Lake	G-7	30,000	217.00
All Wyoming Aqueduct from Bighorn Lake	G-8	30,000	211.00
All Wyoming Aqueduct from Bighorn Lake	G-9	30,000	183.00
Yellowstone River near Armells Creek	G-10	30,000	170.00
Yellowstone River near Armells Creek	G-11	30,000	170.00
Yellowstone River near Armells Creek	G-12	30,000	317.00
Yellowstone River near Armells Creek	G-13	30,000	84.00
Yellowstone River near Armells Creek	G-14	30,000	84.00
Yellowstone River near Armells Creek	G-15	30,000	84.00
Yellowstone River near Armells Creek	G-16	30,000	84.00
Yellowstone River near Armells Creek	G-17	30,000	87.00
Yellowstone River near Armells Creek	G-18	30,000	67.00
Yellowstone River near Armells Creek	G-19	30,000	47.00
Yellowstone River near Armells Creek	G-20	30,000	47.00
Yellowstone River near Armells Creek	G-21	30,000	47.00
Yellowstone River near Armells Creek	G-22	30,000	75.00
Yellowstone River near Armells Creek	G-23	30,000	110.00
Yellowstone River near Armells Creek	G-24	30,000	110.00

Table A-11
COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development-Alternative 3-Lake Oahe to Gillette
Area Transposed
Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered AF/yr.	Total Cost Per AF (Jan. 1973)
Lake Oahe	P-1	23,000	316.00
Lake Oahe	G-1	30,000	370.00
Lake Oahe	G-2	30,000	359.00
Lake Oahe	G-3	30,000	345.00
Lake Oahe	G-4	30,000	335.00
Lake Oahe	G-5	30,000	325.00
Lake Oahe	G-6	30,000	325.00
Lake Oahe	G-7	30,000	362.00
Lake Oahe	G-8	30,000	349.00
Lake Oahe	G-9	30,000	337.00

of water from this delivery system to Sugar Creek would be $140 per acre-foot. The cost of water from Lower Green Reservoir would be about $4 per acre-foot, based on data from page 54 of October 1972 report by the State of Wyoming on development of presently unused water supplies of Green River.

Interest During Construction

The construction period for each of the plans is shown in Tables A-15 through A-28. It varies from 1½ to 6 years. One year's period of time generally as a minimum was assumed to be necessary for preconstruction activities for each plan for right-of-way acquisition, foundation exploration, preparation of design data, preparation of designs and specification, call for bids, and award of contracts. The interest during construction was computed at 8 percent interest for one-half of the capital costs for the full construction period,

Operation and Maintenance

The 85 percent or higher load factor of the steamplants and gasification plants would require that operational and maintenance personnel be on the job throughout the year. Costs to operate and maintain the facilities were computed on this assumption and the premise that each pumping plant would be semiattended. These costs are shown in Tables A-15 through A-28, and the costs generally include costs of items that will need replacement during the amortization period.

Replacements

The project investment period was selected at 40 years. On this premise no replacements would be required for any major component of the conveyance works with a life over 35 years. Bureau of Reclamation experience has indicated that no replacements are necessary for properly-built waterways, pipelines, reservoirs, and surge facilities; and that minor items that are replaced would be treated as maintenance costs. The facilities most likely to need replacements are certain items of the pumping plant. A pumping installation generally consists of cost components as follows:

Component	Percent of Overall Structure Cost (percent)
Structures and Improvements	55
Pumps and prime movers	27
Accessory electrical equipment	11
Miscellaneous equipment	2
Remote control equipment	5

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Approximately 8 percent of the pumps and prime movers would require replacement after 20 years of operation and approximately 10.7 percent after 35 years. Also, about 7 percent of the accessory electrical equipment, not including transmission and transformer facilities, could need replacing after 15 years of operation and 33 percent after 35 years. Miscellaneous mechanical equipment consists of 2 percent of a large pumping installation, and about 4 percent of this would require replacement after 25 years. Remote control equipment was assumed to be completely replaced at least once during the amortization period of the water conveyance facilities.

Power and Energy Costs

The derivation of horsepower installation and energy is based on 80 percent pumping plant efficiency. The $0.008 cost per kilowatt-hour is the cost of energy delivered to the load center and includes any minimum or capacity charge. Transmission losses were assumed to be 8 percent of the load, and the $0.008 cost per kilowatt-hour included capital investment, operation, and maintenance of transmission facilities from load center to pumping plant. The cost of pumping energy is shown in Tables A-15 through A-28.

The source of pumping power was not identified but it was assumed that power would be readily available from either a public utility, rural electric cooperative, or government power facility.

Financial Analysis

Annual costs per acre-foot of water delivered to each site as derived in Tables A-15 through A-28 are of sufficient magnitude to recover all investment, operation, maintenance, replacement, and storage costs. Investment costs are amortized at a rate of 8 percent interest over a 40-year repayment period except for storage costs. This method of amortization of an investment gives equal annual payments which include the principal and interest components.

Investment in large storage reservoirs with capabilities to supply water to multiple ar alternative points of use are amortized over a 50-year period. The useful life of storage facilities is not limited by the recoverable coal reserves and plant life at any one particular site. The storage reservoirs would have a useful life sufficient for two or three successive 40-year periods of plant operation.

The useful life of the conveyance facilities will probably extend some time beyond the 40-year amortization period but no replacements

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were estimated beyond 40 years operation. Also no salvage value has been included in the analysis.

Tables A-15 through A-28 will be of interest to those reviewers and subsequent investigators who may wish more detailed information on each plan. Some pertinent physical data are listed along with the main component of costs. These include the reaches, the length of aqueducts, the capacity, total static and total dynamic pumping heads, construction periods, and interest during construction. From these data the annual pumping energy can be computed and the horsepower per reach derived if needed.

The data for the plans of plant deliveries in Montana and Wyoming are presented by aqueduct reach. The data for delivery schemes to plants in North Dakota are generally summarized by reaches but some of the data are presented by allocation of costs from diversion site to plant site. This occurred because different personnel worked independently under general criteria and summarized data differently. Time did not permit a resummarization for the sake of uniformity.

Storage Costs or Basic Water Charge

This item represents the costs of developing or acquiring a firm water supply whether from an existing reservoir or a new reservoir to be constructed. The cost of buying water on a firm basis is listed in Tables A-15 through A-28 as Basic Water Charge.

All basic water charges from existing reservoirs were computed at a rate of $9 per acre-foot. This includes water diverted from main streams such as the Bighorn, Yellowstone and Missouri Rivers because the diverted water was assumed to be released from storage in one of the reservoirs.

Basic water charges from reservoirs to be constructed were computed from costs allocated to industrial or municipal water storage. The allocation of costs and unit basic charge of water from these reservoirs are shown on Table A-1.

Potential Reservoirs

During the early phase of the study the amount of water that would be necessary to meet the requirements of the scenarios was unknown. Also the sites of the potential steam electric plants and gasification plants were unknown. Because of this and the comprehensiveness of the study, an inventory was undertaken of all potential storage sites that could supply water to the plant sites. Table A-29 is a tabulation of the sites mentioned. Its purpose in this report is to record the sites mentioned, size of reservoir, the source of the costs of the facility and the January 1973 cost. Many sources were researched to compile the data because time did not permit reestimating the cost of the 55 potential dams. The geographical locations of the potential reservoirs are shown on Plates 1 and 2, and further data concerning the reservoirs is given in Table 4 of the main report.

Variables of Water Transmission Costs

To demonstrate the effects of variable interest rates, amortization period, and cost of pumping energy on the costs of water, studies on three routes were undertaken. These routes are: Miles City, Montana, to Gillette, Wyoming; Lake Oahe, South Dakota, to Gillette, Wyoming and Lake Sakakawea, North Dakota, to Cave Hills, South Dakota, each with a fixed capacity. Each was studied employing interest rates of 6 percent through 10 percent and investment period of 30, 40, and 50 years. The effect of the pumping power rate was also analyzed. Graphs were prepared of the effects of these variables on the delivery cost of water through each of the three routes. They are shown in Figures A-1 through A-3.

Another part of this study was to determine the effect on the cost of water delivered to the three delivery points with various capacity pipelines. The variable parameters of interest, power rate, and investment period were fixed at 8 percent, 8 mills per kilowatt-hour and 40 years, respectively, to show the effect of varying the delivery capacity of the aqueducts over the same three routes. The results of these analyses are shown in Figures A-4 through A-6.

Information on Impact from Water Transmission Facilities

During the investigation, information was compiled for use in an appraisal of economic impact resulting from construction, operation, and maintenance of the water transmission facilities. These data were categorized into costs of capital equipment, materials, etc. Size of construction crews to construct the works were estimated as well as the costs and number of people required to operate and maintain the systems. This analysis was made only for Choice 1 of the Most Probable Forecast, for a federally financed system.

In North Dakota the facilities would be constructed during a 3-year construction period involving 700 people in the contractor's forces and 330 government personnel exclusive of designers and specification engineers. The cost breakdown for the various components is shown on Table A-12.

Capital equipment to operate the system is estimated to be $2,600,000. Total OM&R budget per year is estimated to be $900,000 (not including energy cost). Personnel costs are estimated to be $540,000 per year with an average salary of $13,000 per year per person. This would require an average operation and maintenance staff of 42 persons employed as listed below:

Type	Number of Persons
Management	8
Clerical	6
Plant Operators	8
Plant Mechanics	10
Aqueduct Maintenance Crew	10

Similar information was compiled in a slightly different format for the aqueducts from the Bighorn and Yellowstone Rivers to plants in Montana and Wyoming.

Table A-13 is a breakdown of the principal components for the economic impact analysis. This table reflects costs and man-power requirements while Table A-15 is a breakdown of the annual replacement costs of those items of the system that would require replacement during the investment period.

Table A-12

BREAKDOWN FOR TOTAL CONSTRUCTION COST
Most Probable Forecast-Choice 1-North Dakota

Northern Great Plains Resource Program
Work Group (C) Water

Contractor's Construction Cost - 3 year construction		
Materials and Equipment		$92,480,000
a. Cement	($2,350,000)	
b. Reinforcement Steel	(1,680,000)	
c. Concrete Pipe	(55,360,000)	
d. Structural Shapes	(6,760,000)	
e. Building materials	(1,040,000)	
f. Gates and Valves	(3,930,000)	
g. Pumps and Motors	(11,430,000)	
h. Accessory Electrical Equip.	(3,640,000)	
i. Transformers and Substation	(2,080,000)	
j. Metal Products	(2,870,000)	
k. Miscellaneous	(1,340,000)	
Equipment and Supplies		$35,730,000
Contractor's Payroll		$36,950,000
Profit and Overhead		$30,990,000
Total Contractor's Cost		$196,150,000
Land and Rights Cost		$17,160,000
Total Field Cost		$213,310,000
Government Construction Cost		
Designs and Specifications		$14,940,000
Capital Equipment		$14,940,000
Construction Engineer and Supervision		$12,810,000
Total Government Cost		$42,690,000
		$256,000,000

TABLE A-13
BREAKDOWN OF TOTAL CONSTRUCTION COST

NORTHERN GREAT PLAINS RESOURCE PROGRAM
Most Probable Forecast - Choice 1 - Montana-Wyoming

AQUEDUCT & REACH	TOTAL COST ($1000's) 1/	GOVT ON & OFF SITE LABOR & OVERHEAD 2/		CONTRACTOR 2/ ON-SITE LABOR		CONTRACTOR 2/ OFF-SITE LABOR	CONTRACTOR 2/ MATERIALS & EQUIPMENT (CAPITAL EQUIP.)	CONSTRUCTION MAT'L 2/ & EQUIPMENT	O&M	
		($1000's) (21.5%)	(14.5 Man-Yrs. Per $1 x 10^6)	($1000's) (10.5%)	(7.5 Man-Yrs. Per $1 x 10^6)	(29.5 Man-Yrs. Per $1 x 10^6)	($1000's) (13%)	($1000's) (35%)	($1000's)	(Personnel)
HARDIN-GILLETTE										
Hardin to G-5	$ 112,600	$ 24,210	1,633	$ 11,82[illegible]	845	3,320	$ 14,635	$ 39,410	$ 288	54
G-5 to Bifur #1	15,155	3,260	220	1,590	115	445	1,970	5,305	25	↓
Bifur #1 to Ulm	32,220	6,925	467	3,385	240	950	4,190	11,280	138	
Ulm to P-1	35,065	7,540	508	3,680	265	1,035	4,560	12,270	125	
P-1 to G-2	20,855	4,485	302	2,190	155	615	2,710	7,300	82	
Bifur #1 to G-4	9,195	1,975	133	965	70	270	1,195	3,220	28	
G-4 to P-2	7,120	1,530	103	750	55	210	925	2,490	39	
P-2 to P-3	3,800	815	55	400	30	110	495	1,330	13	
Ulm to G-3	14,280	3,070	207	1,500	105	420	1,855	5,000	39	
TOTAL	$ 250,290	$ 53,810	3,630	$ 26,285	1,880	7,375	$ 32,535	$ 87,605	$ 777	
YELLOWSTONE-COLSTRIP TONGUE & SARPY										
Yellowstone to Bifur #1	$ 22,680	$ 4,875	330	$ 2,380	170	670	$ 2,950	$ 7,940	$ 107	43
Bifur #1 to G-8	14,115	3,035	205	1,480	105	415	1,835	4,940	35	↓
G-8 to Bifur #2	8,125	1,745	120	855	60	240	1,055	2,845	28	
Bifur #2 to Bifur #3	29,235	6,285	425	3,070	220	860	3,800	10,230	59	
Bifur #3 to G-9	9,410	2,025	135	990	70	275	1,225	3,295	14	
Bifur #3 to P-4	9,325	2,005	135	980	70	275	1,215	3,265	16	
Bifur #1 to G-6	24,135	5,190	350	2,535	180	710	3,140	8,450	99	
Bifur #2 to G-7	3,890	835	55	410	30	115	505	1,360	19	
TOTAL	$ 120,915	$ 25,995	1,755	$ 12,700	905	3,560	$ 15,725	$42,325	$ 377	
Pumpkin Reservoir to G-1	$ 36,075	$ 7,756	523	$ 3,788	271	1,065	$ 4,690	$12,625	$ 170	37
Fort Peck Lake to P-5	$ 12,515	$ 2,691	181	$ 1,314	94	370	$ 1,625	$ 4,380	$ 71	30

1/ Total Project Investment - IDC
2/ From letter dated January 1972 - (E&R Center) - concerning reclamation costs

Table A-14

ANNUAL REPLACEMENT COSTS
Most Probable Forecast-Choice No. 1

Northern Great Plains Resource Program
Work Group (C) Water

Reach	Pumping Plant	Telemetering	Chlorination Stations	Flow Control Stations	Total Annual Replacement Cost
HARDIN-GILLETTE					
Hardin-G5	$6,900	$6,200	$800	$2,300	$16,200
G5-Bifur	-	800	-	4,000	4,800
Bifur-Ulm	2,600	1,800	600	1,300	6,300
Ulm-P1	1,300	1,900	-	2,500	5,700
P1 - G2	700	1,200	-	-	1,900
Bifur-G4	-	500	-	2,300	2,800
G4 - P2	500	400	-	-	900
P2 - P3	200	200	-	700	1,100
Ulm-G3	200	800	-	400	1,400
Pumpkin Res.-G1	1,700	1,900	400	2,600	6,600
Ft. Peck Lake-P5	700	1,500	400	-	2,600
Yellowstone-Colstrip and Tongue River and Sarpy Creek					
Yellowstone-Bifur No. 1	2,000	1,300	700	-	4,000
Bifur No. 1 - G6	1,200	1,400	-	1,300	3,900
Bifur No. 1 - G8	700	800	-	-	1,500
G8 - Bifur No. 2	600	500	-	-	1,100
Bifur No. 2-Bifur No. 3	300	1,600	-	800	2,700
Bifur No. 3 - G9	-	500	-	600	1,100
Bifur No. 3 - P4	-	500	-	500	1,100
Bifur No. 2 - G7	200	200	-	-	400

Table 8-15
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
BASE FORECAST
CHOICE 1

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 1/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 2/ ($1000's)	Basic Water Charge ($1000's)	Annual Cost Per Reach ($1000's) $/AF	Total Annual Cost $/AF
Moorhead to P-1	24.9	33	23,000	33-51	860	1,096	12,765	2	1,275	3,190	17,230	1,445	97	280	828[3]	115.20	115.20
Tongue Res. to Bifurcation	8.1	56	39,000	42	760	857	6,450	1.5	485	1,615	8,550	718	68	371	1,287[4]	62.60	62.60
Bifurcation to P-2	2.0	28	19,500	27-30	0	0	1,990	1.5	180	495	2,635	220	5	-	-	11.60	74.20
Bifurcation to P-3	7.7	28	19,500	21-27	0	0	3,140	1.5	275	910	4,820	405	17	-	-	21.70	84.30
Tongue Res. to P-4	1.7	28	19,500	30	110	140	1,919	1	110	555	2,885	240	21	30	645[4]	48.00	48.00
Fort Peck Res. to P-5	21.8	28	19,500	33	734	856	10,005	1.5	750	2,500	13,260	1,110	74	185	176[5]	79.20	79.20
Lake Sakakawea to P-6	4.7	33	22,900	36-39	199	200	5,170	3	746	1,034	6,950	580	30	50	206[5]	37.97	37.97

1/ Amortized at 8 percent over 40 years.
2/ Power costs computed at 8 mills/kwh.
3/ Water charge from Moorhead at $36/AF.
4/ Tongue Reservoir charge at $33/AF.
5/ Based on $9/AF main-stem reservoir rate.

Table A-16
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
BASE FORECAST
CHOICE 2

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-75) ($1000's)	Construction Period (Years)	Interest During Construction ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 1/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 2/ ($1000's)	Basic Water Charge ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Hardin to Bifurcation	73	119	81,800	45-60	1,230	1,682	70,010	5	17,230	14,000	101,240	8,500	270	1,522	734 2/	11,026	135.20
Bifurcation to P-1	73.5	31	23,000	27-42	862	1,070	32,506	5	7,800	6,500	46,806	3,925	160	273	3,110 3/	7,468	324.69
Bifurcation to P-2	26.7	84	58,500	33-60	360	402	25,070	5	6,015	5,015	36,100	3,025	74	261	7,909 3/	11,269	192.60
P-2 to P-3	8.1	34	19,500	27-48	0	0	4,287	5	1,700	1,055	7,042	641	19	-	7,511 3/	817	209.50
P-3 to P-4	24.8	26	19,000	27-33	0	0	7,440	5	1,830	1,490	10,760	902	33	-	4,085 3/	5,020	257.40
Flatwillow Res. to P-5	101.6	28	19,500	24-42	552	721	35,350	2½	4,370	8,740	48,060	4,030	191	156	1,443 4/	5,820	298.50
Lake Sakakawea to P-6	4.7	33	22,900	36-39	199	250	5,170	3	746	1,034	6,950	580	90	50	210 2/	866	37.97

1/ Power costs computed at 8 mills/kwh.
2/ Water charge based on $9/AF below Bighorn Reservoir and from Lake Sakawea.
3/ Water charge based on $9/AF below Bighorn Reservoir and prorated portion of aqueduct of preceeding reach.
4/ Based on water charge of $74/AF storage costs of Flatwillow yielding 21,500 AF annually.

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Table A-17
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
MOST PROBABLE FORECAST
CRUISE NO. 1 - MONTANA & WYOMING

Aqueduct and Reach	Length (Miles)	Q (ft³/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-75) ($1000's)	Construction Period (Years)	Interest During Construction 7/ ($1000's)	Administration and General Expense 1/ ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 3/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 4/ ($1000's)	Basic Water Charge ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Hardin-G1	14.84	263	192,000	84	1,270	1,[illegible]	43,420	6	27,720	18,760	139,600	11,705	304	3,225	1,640 5/	92.70	92.70
G1-Bifurcation No. 1	12.90	220	152,000	60	0	0	12,630	6	3,635	2,325	18,790	1,575	30	0	--	10.60	103.30
Bifurcation-Gin	28.84	121	87,000	60	784	1,036	28,830	6	7,730	5,370	39,950	3,350	144	955	--	53.60	156.90
Gin to P-1	47.16	78	55,000	54	100	156	29,220	6	8,415	5,845	43,480	3,645	131	115	--	73.40	230.30
P-1 to G-2	30.74	43	30,000	48	370	410	17,360	6	5,005	3,475	25,860	2,170	84	135	--	79.60	309.90
Bifurcation No. 1 to G-4	6.61	99	69,000	48	0	0	7,660	6	2,205	1,530	11,395	955	31	0	--	14.30	117.60
G-4 to P-2	7.46	56	39,500	42	460	521	5,930	6	1,705	1,185	8,820	740	40	247	--	26.30	143.90
P-2 to P-3	8.33	28	19,500	24	0	0	3,170	6	915	635	4,720	395	14	0	-	21.00	164.90
Gin to G-3	19.07	43	30,000	48	160	219	11,900	6	3,425	2,380	17,705	1,485	40	73	--	57.30	215.20
Yellowstone-Colstrip-Tongue and Sarpy																	
Yellowstone-Bifurcation No. 1	14.90	200	139,500	76	370	474	19,930	4	3,650	3,780	26,310	2,205	111	735	1,255 5/	30.90	30.90
Bifurcation No. 1 to G-4	10.31	137	99,500	72	210	250	11,760	4	2,235	2,350	16,362	1,370	37	310	--	15.70	46.60
G-6 to Bifurcation No. 2	7.38	114	79,000	60	190	241	6,770	4	1,300	1,355	9,422	790	29	220	--	13.10	59.70
Bif. No. 2-Bif. No. 3	30.25	71	49,500	54	110	124	24,360	4	4,675	4,870	33,905	2,845	62	70	--	60.10	119.80
Bifurcation No. 3 to G-9	9.41	43	30,000	48	0	0	7,840	4	1,505	1,570	10,915	915	15	0	--	31.00	150.80
Bifurcation No. 3 to P-4	11.63	28	19,500	42	0	0	7,770	4	1,495	1,555	10,815	905	17	0	--	47.30	167.10
Bifurcation No. 1 to G-6	36.21	43	30,000	42	640	996	20,110	4	3,860	4,020	27,990	2,350	103	330	--	92.80	123.70
Bifurcation No. 2 to G-7	5.79	43	30,000	39	100	144	3,240	4	620	650	4,510	380	20	45	--	14.80	74.50
Pumpkin Reservoir to G-1	68.34	43	30,000	39	1,160	1,430	28,860	2	2,885	7,215 2/	38,960	3,265	177	475	1,350 6/	175.57	175.57
Fort Peck Lake to P-5	21.18	28	19,500	33	734	836	10,010	1.5	750	2,500 2/	13,260	1,110	74	185	175 5/	79.20	79.20

1/ 20 percent.
2/ 25 percent.
3/ 8 percent at 40 years.
4/ 8 mills/kwh.
5/ $5/AF.
6/ Basic water charge at $45/AF.
7/ IDC computed at 8 percent interest over construction period.

Table A-15
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
MOST PROBABLE FORECAST
CHOICE NO. 1 - NORTH DAKOTA

Aqueduct and Reach	Length (Miles)	(ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Lake Sakakawea to G-10, 11 & 12	27.3	129	49,550	57-114	604	740	24,710	3	3,558	4,942	33,210	2,760	120	730	610	4,440	49.56
Sakakawea to P-9	61.6	35	24,310	63-114	1,134	1,400	16,050	3	2,310	3,210	21,570	1,810	70	380	220	2,480	102.02
Sakakawea to P-11	133.9	33	24,310	-	1,540	2,000	34,570	3	4,980	6,914	46,460	3,900	150	540	220	4,810	197.86
Sakakawea to P-8	101.8	33	24,310	-	1,669	1,800	30,400	3	1,164	6,080	40,860	3,430	120	460	220	4,230	174.00
Sakakawea to P-7	129.3	35	24,310	-	1,669	1,800	40,280	3	5,804	8,056	54,140	4,540	160	480	220	5,400	222.13
Sakakawea to G-14	18	43	29,850 5/	-	504	565	8,080	3	6,080	1,616	10,860	910	30	190	270	1,400	46.90
Sakakawea to G-13	22.7	43	29,850 5/	-	504	585	9,770	3	1,406	1,950	13,130	1,100	30	190	270	1,590	53.27
Sakakawea to P-6	43.6	33	24,310	-	654	760	14,920	3	2,146	2,984	20,050	1,680	50	210	220	2,160	88.85
Sakakawea to P-10	62.9	33	24,310	-	929	1,139	24,620	3	3,516	4,924	33,060	2,770	210	310	220	3,410	140.27
Sakakawea to G-16	5	43	29,850 5/	-	299	310	4,340	3	632	868	5,840	490	30	100	270	890	29.82
Sakakawea to G-15	7.9	43	29,850 5/	-	299	310	5,570	3	796	1,114	7,480	630	40	100	270	1,040	34.84

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power costs computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from main stem reservoir.
5/ Gasification Demand = 30,000 AF/Yr. but annual cost of water based on delivery of 29,850 AF/Yr.

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Table A-19
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
MOST PROBABLE FORECAST
CHOICE NO. 2 - MONTANA-WYOMING

Aqueduct and Reach	Length (Miles)	Q (ft³/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-72) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Yellowstone to Bif. No. 1	15.0	342	238,300	96	370	455	25,480	6	7,340	5,095	37,915	3,180	153	1,205	2,147 4/	28.00	28.00
Bifurcation No. 1 to G-6	36.2	43	30,000	27-45	850	996	20,105	6	2,790	4,020	29,915	2,510	103	332		98.20	126.20
Bifurcation No. 1 to G-8	10.5	299	208,300	90	215	259	16,427	6	4,729	3,284	24,435	2,049	46	599		12.90	40.90
G-8 to Bifurcation No. 2	7.4	256	178,300	84	190	240	11,035	6	3,180	2,205	16,420	1,377	38	476		10.60	51.50
Bifurcation No. 2 to G-7	3.8	43	30,000	39	100	140	3,240	6	935	650	4,825	405	20	45		15.70	67.20
Bif. No. 2 to Bif. No. 3	30.3	213	148,300	60-90	110	120	53,260	6	15,340	10,650	79,250	6,645	77	198		4[illegible].60	98.10
Bifurcation No. 3 to G-9	9.8	43	30,000	45-48	0	0	7,840	6	2,260	1,570	11,670	979	15	0		33.10	131.20
Bifurcation No. 3 to P-4	11.6	170	118,300	78	0	0	19,695	6	5,670	3,940	29,305	2,458	23	0		20.90	119.00
P-4 to P-3	25.9	142	99,000	66	385	527	27,060	6	7,790	5,410	40,260	3,375	82	579		40.80	159.80
P-3 to P-2	8.1	114	79,500	60	510	573	8,745	6	2,530	1,755	13,070	1,096	49	506		20.80	180.60
P-2 to G-4	7.8	86	60,000	54	0	0	7,570	6	2,180	1,515	11,265	945	13	0		16.00	196.60
G-4 to G-5	21.9	43	30,000	39-45	170	203	15,685	6	4,515	3,135	23,335	1,955	46	68		69.00	265.60
Moorhead Res. to P-1	26.0	121	83,000	60-78	860	1,009	27,585	4	5,515	6,895	39,995	3,355	156	930	2,988 5/	89.50	89.50
P-1 to G-2	23.9	86	60,000	51-72	247	392	19,115	4	3,820	4,780	27,715	2,325	68	261		44.20	133.70
G-2 to G-1	72.6	43	30,000	36-51	640	778	31,415	4	6,280	7,850	45,545	3,820	155	259		141.00	274.70
Box Elder to G-3	6.9	43	30,000	39	180	253	5,035	1½	380	1,260	5,035	560	18	85	1,320 6/	66.00	66.10
Fort Peck Lake to P-5	21.8	28	19,500	33	734	856	10,010	1½	730	2,500	13,260	1,110	74	185	175 4/	79.20	79.20

1/ IDC computed at 8 percent interest over construction period.
2/ Investment amortized over 40 years at 8 percent interest.
3/ Power costs computed at 8 mills/kwh.
4/ Water charged based on $9/AF from existing reservoirs.
5/ Includes cost of water from Moorhead Reservoir at $36/AF.
6/ Includes cost of water from Box Elder Reservoir at $44/AF.

Table A-20
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
MOST PROBABLE FORECAST
CHOICE NO. 2 - NORTH DAKOTA

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Lake Sakakawea to Bifurcation	13.7	164	114,000	66-72	--	575	18,423	3	2,653	3,685	24,761	2,076		730	1,026		
Lake Sakakawea to G-10,G-11,G-12	27.3	129	90,000	57-63	--	740	26,120	3	3,756	5,224	35,100	2,940	160	730	810	4,640	51.81
Lake Sakakawea to P-9	58.0	35	24,310	33-42	--	1,335	26,310	3	3,788	5,262	35,360	2,970	360	140	220	3,690	151.79
Mott Reservoir to P-7	1	35	24,310	33-63	--	155	2,350	3	340	470	3,160	260	40	10	1,993 5/	2,303	94.73
Mott Reservoir to P-8	22	35	24,310	48-60	--	155	8,020	3	1,144	1,606	10,770	900	80	40	1,993 5/	3,013	123.94
Mott Reservoir to P-11	57	35	24,310	30-48	--	845	25,670	3	3,696	5,134	34,500	2,890	230	140	1,993 5/	5,253	216.08
Lake Sakakawea to G-14	52.2	242	30,000	42-90	--	805	18,200	3	2,620	3,640	24,460	2,050	230	80	270	2,630	88.11
Lake Sakakawea to G-13	40.6	43	30,000	42-90	--	805	15,890	3	2,290	3,180	21,360	1,790	230	70	270	2,360	79.06
Lake Sakakawea to P-6	25.5	35	24,310	54-90	--	595	8,140	3	1,172	1,628	10,940	920	130	40	220	1,310	53.89
Lake Sakakawea to P-10	44.8	35	24,310	30	--	950	17,840	3	2,572	3,568	23,980	2,010	230	90	220	2,550	104.90
Lake Sakakawea to G-15	7.9	43	30,000	78-90	--	310	3,940	3	572	788	5,300	440	100	20	270	830	27.81
Lake Sakakawea to G-16	5	242	30,000	78-90	--	310	3,490	3	502	698	4,690	390	100	20	270	780	26.13

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power cost computed at 8 mills/kwh.
4/ Basic water charge at 9/AF from main stem reservoirs.
5/ Basic water charge from Mott Reservoir at $82/AF.

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Table A-21
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT
MONTANA - WYOMING
CHOICE 1

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Big Horn R. at Hardin G-13-G-16	29.4	544	379,500	108-120	660	746	86,685	6	24,956	17,340	128,990	10,815	290	3,142	3,416	46.60	46.60
G-13 - G-16 to G-19 - G-21	24.3	372	259,500	72-102	323	350	52,155	6	15,020	10,430	77,605	6,510	96	1,008	--	29.40	76.00
G-19 - G-21 to G-18	12.4	86	60,000	54	--	--	10,055	6	2,895	2,010	14,960	1,255	18	--	--	21.20	97.20
G-18 to G-17	6.02	43	30,000	42	--	--	4,845	6	1,395	970	7,210	605	3	--	--	20.30	117.50
G-19 - G-21 to G-22	13.0	43	30,000	27-39	--	--	6,416	6	1,848	1,283	9,547	801	79	--	--	29.30	105.30
G-19 - G-21 to Bifurcation #1	28.8	114	79,800	48-72	---	--	32,196	6	9,272	6,439	47,907	4,017	70	--	--	51.40	127.40
Bifurcation #1 to P-4	11.6	28	19,500	42	--	--	7,854	6	2,262	1,571	11,687	980	17	--	--	51.10	178.50
Bifurcation #1 to G-23,G-24	9.8	86	60,000	60	--	--	12,392	6	3,569	2,478	18,439	1,546	18	--	--	26.10	153.50
Big Horn R. at Hardin to Bif. #1	34.1	607	418,500	114-144	610	868	93,815	6	27,020	18,765	139,600	11,707	317	4,032	3,766	47.40	47.40
Bifurcation #1 to G-12	12.1	43	30,000	39	660	787	8,256	6	2,378	1,651	12,285	1,030	59	262	--	45.05	92.45
Bif. #1 to Bif. #2	38.9	564	388,500	84-114	620	740	110,110	6	31,710	22,020	163,840	13,739	228	3,191	--	44.20	91.60
Bif. #2 to G-10, G-11	23.4	142	99,000	60-72	210	221	30,730	6	8,850	6,145	45,725	3,834	60	243	--	41.80	133.40
G-10, G-11 to P-2	3.3	56	39,000	45	150	178	3,294	6	949	659	4,902	411	20	77	--	13.00	146.40
P-2 to P-3	8.1	28	19,500	21-39	--	--	3,233	6	931	647	4,811	403	13	--	--	21.40	167.80
Bif. #2 to Bif. #3	26.4	422	293,000	90-120	746	844	66,010	6	19,010	13,200	98,220	8,236	158	2,745	--	38.00	129.60
Bifurcation #3 to G-9	18.7	129	90,000	66-72	160	193	20,592	6	5,930	4,118	30,640	2,569	51	193	--	31.30	160.90
G-9 to Bifurcation #3A	6.9	86	60,000	54	120	201	5,698	6	1,641	1,140	8,479	711	26	134	--	14.60	175.50
Bifurcation #3A to G-7	6.6	43	30,000	24-42	--	--	4,512	6	1,299	902	6,714	563	13	--	--	19.20	194.70
Bifurcation #3A to G-8	5.4	43	30,000	33	--	--	3,158	6	910	632	4,700	394	9	--	--	13.40	188.90
Bifurcation #3 to P-1	47.1	293	203,000	60-96	116	230	91,269	6	26,286	18,254	135,809	11,389	182	518	--	59.60	189.20
P-1 to G-5, G-6	13.4	258	180,000	96	80	139	22,265	6	6,412	4,453	33,130	2,778	49	278	--	17.30	206.50
G-5, G-6 to G-4	11.5	172	120,000	84	130	150	15,421	6	4,441	3,084	22,946	1,924	40	200	--	18.00	224.50
G-4 to G-3	5.9	129	90,000	78	90	104	8,429	6	2,428	1,686	12,543	1,052	28	104	--	13.20	237.20
G-3 to G-2	11.9	86	60,000	66	290	322	12,395	6	3,570	2,479	18,444	1,547	54	214	--	30.20	267.90
G-2 to G-1	60.7	43	30,000	36-45	350	453	24,282	6	6,993	4,856	36,131	3,030	117	151	--	109.90	377.80

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power cost computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from existing reservoir.

Table A-22
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT
NORTH DAKOTA
CHOICE 1

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Lake Sakakawea to G-26 thru 32	27	301	210,000			750	56,830	3	8,190	11,360	76,380	6,400	200	1,720	1,880	10,200	48.81
Lake Sakakawea to P-9	62	35	24,310			1,400	14,750	3	2,120	2,950	19,820	1,660	60	380	220	2,320	95.43
Lake Sakakawea to G-25	72	43	30,000			1,590	21,100		3,050	4,220	28,370	2,380	80	530	270	3,260	109.21
Lake Sakakawea to P-11	104	35	24,310			595	31,400		4,520	6,280	42,200	3,540	120	590	220	4,470	181.63
Lake Sakakawea to G-42	92	43	30,000			1,985	26,700		3,850	5,340	35,890	3,010	100	660	270	4,040	135.34
Lake Sakakawea to P-8	102	35	24,310			1,985	25,090		3,612	5,018	33,720	2,830	100	540	220	3,690	151.79
Lake Sakakawea to P-7	129	35	24,310			1,985	34,990		5,042	6,998	47,030	3,940	140	540	220	4,840	199.10
Lake Sakakawea to G-35, G-36	32	86	60,000			580	12,770		1,836	2,554	17,160	1,440	40	370	540	2,390	40.03
Lake Sakakawea to G-33, G-34	35	86	60,000			780	16,270		2,336	3,254	21,860	1,830	80	500	540	2,950	49.41
Lake Sakakawea to G-37	33	43	30,000			730	8,540		1,232	1,708	11,480	960	40	250	270	1,520	50.92
Lake Sakakawea to G-38	44	43	30,000			780	9,250		1,330	1,850	12,430	1,040	40	270	270	1,620	54.27
Lake Sakakawea to P-6	50.5	35	24,310			940	9,260		1,328	1,852	12,440	1,040	40	260	220	1,560	64.17
Lake Sakakawea to P-10	70.9	35	24,310			1,300	18,960		2,728	3,792	25,480	2,140	100	350	220	2,810	115.59
Lake Sakakawea to G-39, 40, 41	68.5	129	90,000			1,140	44,510	3	6,408	8,902	59,820	5,020	190	1,130	800	7,140	79.73

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power costs computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from main stem reservoir.

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Table A-23
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT - CHOICE NO. 2
MONTANA-WYOMING

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Yellowstone-Bifurcation No. 1	14.96	1,100	768,000	144	370	472	66,260	6	19,080	13,250	98,390	8,270	400	4,024	6,912	25.50	25.50
Bif. No. 1 - G-13,14,15,16	36.21	172	120,000	66	850	1,008	44,110	↑	12,700	8,820	65,630	5,504	148	1,343	--	58.30	83.80
Bif. No. 1 - Colstrip (G-19, 20, 21)	17.89	928	648,000	138	400	506	80,020		23,045	16,005	119,070	9,985	165	3,640	--	21.30	46.80
Colstrip - G-22	12.99	43	30,000	39	0	0	6,416		1,849	1,283	9,547	802	79	0	--	29.30	76.10
Colstrip - G-18	12.42	86	60,000	54	0	0	10,055		2,895	2,010	14,960	1,255	18	0	--	21.20	68.00
G-18 - G-17	6.02	43	30,000	42	0	0	4,845		1,395	970	7,210	605	3	0	--	20.30	88.30
Colstrip - Bifurcation No. 2	30.25	670	468,000	138	110	120	121,300		34,935	24,260	180,495	15,135	122	628	--	33.90	80.70
Bifurcation No. 2 - G-23,24	9.81	329	229,500	102	0	0	26,231		6,696	5,246	38,173	3,201	24	0	--	14.00	94.70
G-23, 24 - P-1	111.67	243	169,500	84	1,170	1,525	162,475		46,793	32,495	241,763	20,274	388	2,869	--	138.80	233.50
P-1 - G-5, 6	13.35	215	150,000	90	80	136	20,506		5,906	4,101	30,513	2,559	88	226	--	19.20	252.70
G-5, 6 - G-4	11.53	129	90,000	78	130	146	13,865		3,993	2,773	20,631	1,730	37	146	--	21.30	274.00
G-4 - G-3	5.85	86	60,000	66	90	106	6,910		1,990	1,382	10,282	862	25	71	--	16.00	290.00
G-3 - G-2	11.91	43	30,000	48	290	332	8,032		2,313	1,606	11,951	1,002	31	111	--	38.10	328.10
Bifurcation No. 2 - P-4	11.63	341	238,500	102	0	0	30,595		8,810	6,120	45,525	3,818	27	0	--	16.10	96.80
P-4 - P-3	25.90	314	219,000	90	385	522	41,180		11,860	8,235	61,275	5,139	106	1,269	--	29.70	126.50
P-3 - P-2	8.14	286	199,500	84	510	577	15,795		4,550	3,160	23,505	1,970	67	1,278	--	16.60	143.10
P-2 - G-10, 11	7.77	258	180,000	72	0	0	12,680		3,650	2,535	18,865	1,582	21	0	--	8.90	152.00
G-10, 11 - Bifurcation No. 3	8.71	172	120,000	66	0	0	9,055		2,610	1,810	13,475	1,130	17	0	--	9.60	161.60
Bifurcation No. 3 - G-12	21.78	43	30,000	39	460	537	30,774		8,863	6,155	45,792	3,840	59	179	--	135.90	297.50
Bifurcation No. 3 - G-9	47.56	129	90,000	60	944	1,228	47,420		13,655	9,485	70,560	5,917	196	1,227	--	81.60	243.20
G-9 - Bifurcation No. 4	6.89	86	60,000	54	120	201	5,698		1,641	1,140	8,479	711	28	134	--	14.60	257.80
Bifurcation No. 4 - G-7	6.55	43	30,000	30	0	0	4,512	↓	1,299	902	6,714	563	13	0	--	19.20	277.00
Bifurcation No. 4 - G-8	5.44	43	30,000	33	0	0	3,158	6	910	632	4,700	394	9	0	--	13.40	271.20
North Platte to G-1	47.4	43	30,000	27-45	400	482	18,757	2	1,876	4,689	25,322	2,124	107	161	3,699 5/	203.04	203.04
Fort Peck Lake to P-5	21.8	28	19,500	33	734	856	10,005	2½	750	2,500	13,260	1,110	74	185	176 4/	79.20	79.20

1/ Interest during construction based on 6-year construction period and 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent interest.
3/ Power cost computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from existing reservoir.
5/ Basic water charge at $123.31/AF from Kendall Reservoir via Pathfinder Reservoir to North Platte River.

Table A-24
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT - CHOICE 2 - NORTH DAKOTA

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Missouri River Downstream of Lake Sakakawea																	
to P-6	2.5	35	24,310			330	2,800	3	440	560	3,800	320	11	89	220	640	26
to P-10	21.6	35	24,310			685	12,500	3	1,800	2,500	16,800	1,410	71	184	220	1,885	78
to G-38	8.5	43	30,000			330	4,200		560	840	5,600	470	15	109	270	864	29
to G-35, 36	21.5	86	60,000			480	12,200	↑	1,860	2,440	16,500	3,060	39	317	540	3,956	66
to G-37	22.5	43	30,000			630	8,400		1,220	1,680	11,300	950	36	209	270	1,465	49
to G-33, 34	24.5	86	60,000			680	15,700		2,260	3,140	21,100	1,770	69	450	540	2,829	47
to G-26 thru 32	59.5	301	210,000			1,130	97,900		14,120	19,580	131,600	11,030	355	2,611	1,880	15,876	76
to G-25	92.5	43	30,000			1,810	26,400		3,820	5,280	35,500	2,970	118	617	270	3,975	133
to P-9	102.5	35	24,310			1,990	29,600		4,280	5,920	39,800	3,340	126	530	220	4,220	173
to G-42	97.5	43	30,000			2,120	24,300		3,440	4,860	32,600	2,730	115	700	270	3,815	128
to P-11	118.0	35	24,310			2,320	31,100		4,380	6,220	41,700	3,500	136	624	220	4,480	184
to P-8	116.0	35	24,310			2,320	23,100	↓	3,380	4,620	31,100	2,610	104	570	220	3,504	144
to P-7	144.0	35	24,310			2,320	33,000	3	4,800	6,600	44,400	3,720	147	570	220	4,657	192
Missouri River Downstream of Lake Sakakawea																	
to G-39 thru 41	11.0	129	90,000			415	13,700	3	1,960	2,740	18,400	1,540	96	411	800	2,847	32

1/ Interest during construction computed at 8 percent interest rate.
2/ Investments amortized over 40 years at 8 percent.
3/ Power costs computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from main stem reservoir.

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Table A-25
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT
CHOICE NO. 3

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Miles City to Camps Pass	65.3	999	689,500	144	955	1,348	247,315	6	71,225	49,465	368,005	30,861	745	10,452	6,287	69.20	69.20
Camps Pass to P-1	91.1	275	192,500	90	1,000	1,258	118,970	6	34,265	23,795	177,030	14,845	403	2,688		93.20	162.40
P-1 to G-5, 6	13.4	247	173,000	102	80	110	21,875	6	6,300	4,375	32,550	2,730	49	211		17.30	179.70
G-5, 6 to G-4	11.5	129	90,000	78	130	146	13,865	6	3,995	2,775	20,635	1,730	37	146		21.30	201.00
G-4 to G-3	5.9	86	60,000	66	90	106	6,910	6	1,990	1,380	10,280	862	25	71		16.00	217.00
G-3 to G-2	11.9	43	30,000	48	290	332	8,145	6	2,345	1,630	12,120	1,015	39	111		38.80	255.80
Camps Pass to G-23, 24	23.7	724	506,000	108	300	347	75,785	6	21,825	15,155	112,765	9,456	310	1,949		23.20	92.40
G-23, 24 to Bifur. No. 2	6.6	638	446,000	120	0	0	14,185	6	4,085	2,835	21,105	1,770	13	0		4.00	96.40
Bifur. No. 2 to Bifur. No. 3	24.2	450	314,000	102	0	0	57,855	6	16,660	11,570	86,085	7,219	87	0		23.20	119.60
Bifur. No. 3 to G-19, 20, 21	9.3	301	210,000	84	300	373	16,345	6	4,710	3,270	24,325	2,040	70	869		14.20	133.80
G-19, 20, 21 to G-13 thru 16	23.1	172	120,000	72	390	419	30,905	6	8,900	6,180	45,985	3,856	128	558		37.90	171.70
Bifur. No. 2 to P-4	11.0	188	132,000	60	0	0	12,140	6	3,495	2,430	18,065	1,515	20	0		11.60	108.00
P-4 to P-3	25.9	142	99,000	66	385	527	25,200	6	7,260	5,040	37,500	3,145	81	579		38.40	146.40
P-3 to P-2	8.1	114	79,500	60	510	573	9,795	6	2,820	1,960	14,575	1,222	48	506		22.30	168.70
P-2 to G-10, 11	7.8	86	60,000	45	0	0	6,495	6	1,870	1,300	9,665	810	15	0		13.80	182.50
Bifur. No. 3 to G-18	13.2	86	60,000	66	100	120	11,600	6	3,340	2,320	17,260	1,448	39	80		26.10	145.70
[illegible]-18 to G-17	5.4	43	30,000	60	70	94	4,860	6	1,400	970	7,230	607	22	31		22.00	167.70
Bifur. No. 3 to G-22	6.3	43	30,000	36	0	0	3,710	6	1,070	740	5,520	463	10	0		15.80	135.40
Little Bighorn Res. to G-12	31.7	43	30,000	45-51	0	0	20,665	2	2,065	5,165	27,895	2,339	13	0	1,050 5/	113.80	113.80
Arvada Reservoir to G-8	35.0	129	90,000	66	520	730	33,360	3	5,005	8,340	46,705	3,916	120	729	5,040 6/	108.90	108.90
G-8 to Bifur.	5.0	86	60,000	54	160	199	3,675	3	550	920	5,145	431	24	133		9.80	118.70
Bifur. to G-7	6.6	43	30,000	24-39	260	298	4,970	3	745	1,240	6,955	583	31	99		23.80	142.50
Bifur. to G-9	6.9	43	30,000	39-42	170	192	4,650	3	700	1,165	6,515	546	25	64		21.20	139.90

1/ Interest during construction computed at 8% interest rate

2/ Investment amortized over 40 years at 8%

3/ Power cost computed at 8 mills/kwh

4/ Basic water charge at $9/A.F.

5/ Based on water charge of $35/A.F. Storage cost of Little Bighorn Reservoir yielding 40,000 A.F. annually.

6/ Based on water charge of $56/A.F. Storage cost of Arvada Reservoir yielding 65,000 A.F. annually.

Table A-26
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT - ALTERNATIVE 3
NORTH DAKOTA

Aqueduct and Reach	Length (Miles)	Q (ft³/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach ($1000's)	Total Annual Cost $/AF
Lake Sakakawea to																	
G-26 thru 32	27	314	210,000			750	60,270	3	8,676	12,054	81,000	6,790	220	1,790	1,960	10,760	49.36
P-9	62	47	32,630 5/			1,400	19,410		2,798	3,882	26,090	2,190	70	810	290	3,060	93.78
G-25	72	43	30,000			1,590	21,240		3,062	4,248	28,550	2,390	80	530	270	3,270	109.55
P-11	104	35	24,310			2,188	31,510		4,548	6,302	42,360	3,550	120	590	220	4,480	184.29
G-42	92	43	30,000			1,985	26,830		3,864	5,366	36,060	3,020	100	660	270	4,050	135.68
P-8	102	35	24,310			1,985	25,210		3,628	5,042	33,880	2,840	90	530	220	3,680	151.38
P-7	129	35	24,310			1,985	35,110		5,048	7,022	47,180	3,960	140	530	220	4,850	199.51
G-35, 36	32	101	70,110 6/			580	14,700		2,120	2,940	19,760	1,660	50	480	630	2,790	39.79
G-37	33	43	24,310			730	8,590		1,232	1,718	11,540	970	40	240	270	1,520	50.92
G-33, 34	35	86	60,000			780	16,380		2,354	3,276	22,010	1,850	80	810	540	2,980	49.92
G-38	44	43	30,000			780	9,230		1,324	1,846	12,400	1,040	30	250	270	1,590	53.27
P-6	50.5	45	31,240 7/			940	11,390		1,642	2,278	15,310	1,280	40	320	280	1,920	61.46
P-10	70.9	35	24,310			1,300	18,920		2,716	3,784	25,420	2,130	70	340	220	2,780	114.36
G-39 thru 41	68.5	129	90,000			1,140	44,360	3	6,388	8,872	59,620	5,000	190	1,110	810	7,110	79.40

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power cost computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from main stem reservoir.
5/ 12 ft³/s for municipal water.
6/ 15 ft³/s for municipal water.
7/ 10 ft³/s for municipal water.

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Table A-27
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT - ALTERNATIVE 3
YELLOWSTONE BASIN

Aqueduct and Reach	Length (Miles)	Q (ft^3/s)	AF/Yr. (1000's)	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Yellowstone - Bif. No. 1	14.96	767	536	126	370	476	52,861	5	12,687	10,572	76,120	6,383	286	2,832	4,824 4/	26.70	26.70
Bif. No. 1 - G-13,14,15,16	36.21	172	120	66	880	1,008	44,279		10,627	8,856	63,762	5,347	149	1,343	--	57.00	83.70
Bif. No. 1 - Colstrip (G-19, 20, 21)	17.89	395	416	114	400	510	49,270		11,825	9,854	70,949	5,950	149	2,355	--	20.30	47.00
Colstrip - G-22	12.99	43	30	39	0	0	6,351		1,524	1,270	9,145	767	79	0	--	28.20	75.20
Colstrip - G-18	12.42	86	60	54	0	0	9,956		2,389	1,991	14,336	1,202	18	0	--	20.30	67.30
G-18 - G-17	6.02	43	30	42	0	0	4,799		1,152	960	6,911	580	3	0	--	19.30	86.60
Colstrip - Bifurcation No. 2	30.25	337	236	108	110	118	74,827		17,958	14,965	107,750	9,036	94	309	--	40.00	87.00
Bifurcation No. 2 - G-23, 24	9.81	86	60	60	0	0	11,454		2,749	2,291	16,494	1,383	17	0	--	23.30	110.30
Bifurcation No. 2 - P-4	11.63	251	176	90	0	0	25,585		6,140	5,115	36,840	3,090	25	0	--	17.70	104.70
P-4 - P-3	25.90	185	129	72	385	538	28,961		6,950	5,792	41,703	3,497	88	770	--	33.80	138.50
P-3 - P-2	8.14	157	109.5	66	510	583	11,415		2,740	2,283	16,440	1,380	53	709	--	19.60	158.10
P-2 - G-10, 11	7.77	129	90	54	0	0	8,499		2,040	1,700	12,239	1,026	15	0	--	11.60	169.70
G-10, 11 - Bif. No. 3	8.71	43	30	39	0	0	3,652		876	730	5,258	441	13	0	--	14.70	184.40
Bifurcation No. 3 - G-12	21.78	43	30	39	460	537	30,896	5	7,415	6,179	44,490	3,731	58	179	--	132.70	316.70
ALL WYOMING AQUEDUCT FROM BIGHORN LAKE																	
Bighorn Lake - Ulm	94.0	447	312.5	102	2,518	2,664	284,655		81,980	56,930	423,565	35,520	668	9,240	3,438 5/	151.80	151.80
Ulm - G-9	18.71	129	90	66	160	193	20,652		5,948	4,130	30,730	2,577	50	193	--	31.30	183.10
G-9 - Bifurcation No. 1	6.89	86	60	54	120	201	5,698		1,641	1,140	8,479	711	28	134	--	14.60	197.70
Bifurcation No. 1 to G-7	6.55	43	30	30	0	0	4,512		1,290	902	6,714	563	13	--	--	19.20	216.90
Bifurcation No. 1 to G-8	5.44	43	30	33	0	0	3,158		910	632	4,700	394	9	--	--	13.40	211.10
Ulm to P-1	93.68	318	222.5	90	680	1,027	167,490		48,235	33,500	249,225	20,900	532	2,536	--	107.70	259.50
P-1 to G-5, 6	10.13	290	203	84	0	0	16,670		4,800	3,335	24,805	2,080	20	--	--	10.30	269.80
G-5, 6 to G-4	7.20	172	120	72	210	259	9,380		2,700	1,875	13,955	1,170	32	345	--	12.90	282.70
G-4 to G-3	8.80	129	90	54	0	0	7,510		2,160	1,500	11,170	935	15	--	--	10.60	293.30
G-3 to G-2	9.85	86	60	54	0	0	6,330		1,825	1,265	9,420	790	15	--	--	13.40	306.70
G-2 to G-1	3.50	43	30	33	0	0	2,625		755	525	3,905	325	6	--	--	11.00	317.70

1/ Interest during construction computed at 8 percent interest rate for 5-year construction period.
2/ Investment amortized over 40 years at 8 percent.
3/ Power costs computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from Yellowstone River.
5/ Basic water charge at $11/AF from Bighorn Lake.

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Table A-28
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT
ALTERNATIVE 5 - GILLETTE AREA TRANSPOSED

Aqueduct and Reach	Length (Miles)	Q (ft³/s)	AF/Yr.	Size (In-Diam)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-73) ($1000's)	Construction Period (Years)	Interest During Construction 1/ ($1000's)	Administration and General Expense ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 2/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 3/ ($1000's)	Basic Water Charge 4/ ($1000's)	Annual Cost Per Reach $/AF	Total Annual Cost $/AF
Lake Oahe to near Gillette	240	432	316,000	108	--	--	588,170	5	141,169	117,624	846,963	71,026	1,901	16,084	2,844	293.53	293.53
Gillette to P-1	16.76	437	312,000	102	140	214	30,715	6	8,845	6,145	45,705	3,835	125	760	--	15.15	316.03
P-1 to G-5, 6	10.13	419	245,000	96	0	0	19,970	↑	5,750	3,995	29,715	2,496	21	--	--	8.50	324.53
G-5, 6 to G-4 5/	7.20	290	213,000	90	210	255	11,625		3,350	2,325	17,300	1,450	36	595	--	10.20	334.73
G-4 to G-3	8.85	129	90,000	54	0	0	7,510		2,160	1,500	11,170	935	15	--	--	10.60	345.33
G-3 to G-2	9.55	86	60,000	54	0	0	6,330		1,825	1,265	9,420	790	15	--	--	13.40	358.73
G-2 to G-1	5.50	43	30,000	33	0	0	2,825		755	325	3,905	325	6	--	--	11.00	369.73
G-5, 6 to G-9	4.30	43	30,000	33	0	8	2,945		850	590	4,385	370	8	--	--	12.60	337.13
G-4 to G-8	6.25	86	60,000	54	100	148	5,725	↓	1,450	1,145	8,320	715	24	100	--	14.00	348.73
G-8 to G-7	5.96	43	30,000	36	0	0	3,150	6	910	630	4,690	395	10	--	--	13.50	362.23

1/ Interest during construction computed at 8 percent interest rate.
2/ Investment amortized over 40 years at 8 percent.
3/ Power costs computed at 8 mills/kwh.
4/ Basic water charge at $9/AF from main stem reservoir.
5/ Turnout for 32 c.f.s. municipal water.

Sheet 1 of 3

Table A-29
COST OF POTENTIAL STORAGE RESERVOIRS
NORTHERN GREAT PLAINS RESOURCE PROGRAM
WORK GROUP (C) WATER

No.	Name of Storage Site	Stream and Location	Approximate Capacity of Maximum without Surcharge A.F.	Cost from Report	Date of Estimate Prices as of-	Cost Index Jan. 1973	Approximate Cost Jan. 1973 Does Not Include IDC	Source of Cost Information	Alternatives For-Or Remarks
1	[illegible]	Yellowstone River	1,092,000	$ 67,562,000	Jan. 1961	1.65	111,500,000	October 1963 Report	Plan No. 2 Power Facilities Excluded
2	Allenspur	Yellowstone Ab. Livingston, Mont.-w/o P.P.	4,000,000	69,083,000	Jan. 1961	1.65	114,000,000	Yellowstone Div. Report	Power Facilities Excluded
3	Absaroka	Yellowstone River	1,072,000	85,600	July 1959	1.60	137,000,000	Regional Office Studies 1960-1961	Used large size - Power Fac. Excluded
4	Lissa (Tullock)	Yellowstone River	2,405,000	68,100,000	Mar. 1960	1.60	109,000,000	Regional Office Studies 1960-1961	Used plan 2 - Power Fac. Excluded
5	Buffalo Creek	Offstream Nr. Custer, Mont.	72,700	[illegible]	Jan. 1970	1.14	36,600,000	Miss.-Yellowstone Trib. Oct. 1970	Includes Pump, Plant, Trans. Line & Fishery
6	Cedar Ridge	Offstream Nr. Hysham, Mont.	126,800	19,430,000	Jan. 1970	1.14	24,210,000	Miss.-Yellowstone Trib. Oct. 1970	Includes Pump, Plant, Trans. Line & Fishery
7	Sunday Creek	Offstream Nr. Miles City, Mont.	678,000		Jan. 1973		113,000,000	Estimated by D&C for N.G.P.R.P.	
8	Lignite Creek	Offstream Nr. Miles City, Mont.	30,000		Jan. 1973		15,930,000	Estimated by D&C for N.G.P.R.P.	
9	Sweeney Creek	Offstream Nr. Forsyth, Mont.	116,000		Jan. 1973		44,900,000	Estimated by D&C for N.G.P.R.P.	
10	Moon Creek	Offstream Nr. Miles City, Mont.	150,000		Jan. 1973		50,240,000	Estimated by D&C for N.G.P.R.P.	
11	Tullock Creek	Offstream Nr. Bighorn River	270,000		Jan. 1973		64,080,000	Estimated by D&C for N.G.P.R.P.	
12	Canyon Creek	Offstream Nr. Billings, Mont.	575,000		Jan. 1973		90,000,000	Estimated by D&C for N.G.P.R.P.	Includes R.R. Relocation
13	Wilsall	Shields River Nr. Wilsall, Mont.	81,000		Jan. 1973		17,760,000	Estimated by D&C for N.G.P.R.P.	
14	Shields R. Storage	Potter Cr. Nr. Wilsall, Mont.	220,000		Jan. 1973		18,970,000	Estimated by D&C for N.G.P.R.P.	
15	Brackett Creek	Brackett Cr. Nr. Livingston, Mont.	38,000		Jan. 1973		13,900,000	Estimated by D&C for N.G.P.R.P.	
16	Natural Bridge	Boulder River	35,000	900,000	1940	3.55	3,200,000	1942 Recon. Report on Boulder River	
17	Rosebud Creek	6 Miles NE Colstrip, Mont.	108,000		Jan. 1973		19,920,000	Estimated by D&C for N.G.P.R.P.	
18	Hunter Mountain	Clarks Fork Yellowstone	130,000	9,054,000	July 1956	1.78	16,075,000	Clarks Fork Div. Appendix I, May 1957	Cost Excludes Power Facilities
19	Thief Creek	Clarks Fork Yellowstone	200,000	24,914,000	July 1956	1.78	44,230,000	Clarks Fork Div. Appendix I, May 1957	
20	Baldridge	Clarks Fork Yellowstone	14,600	5,619,000	July 1956	1.78	9,975,000	Clarks Fork Div. Appendix I, May 1957	Cost Excludes Power Facilities
21	Sunlight	Sunlight Creek	50,000	2,327,000	July 1956	1.78	4,130,000	Clarks Fork Div. Appendix I, May 1957	Cost Excludes Power Facilities
22	Flatwillow	2 Miles Ab. Muss.	70,800	11,668,000	June 1966	1.51	17,630,000	Lower Musselshell Unit Nov. 1966	
23	Custer	Bighorn River Nr. Mouth	[illegible]		Jan. 1973		25,000,000	Estimated by D&C for N.G.P.R.P.	
24	Little Bighorn	L. Bighorn S. 17, T. [illegible] S., R. 34 E.	65,000	22,450,000	Jan. 1970	1.14	27,950,000	Miss.-Yellowstone Tribs. Oct. 1970	Mt-Wyo Aqueducts Report shows $31,228,000
25	Buffalo Bill Enl.	Shoshone River Ab. Cody, Wyo.	710,000	22,560,000	Oct. 1972	1.22	26,250,000	Letter from E&R 1/30/73" & Gt. Falls 3/13/73	Includes $489,000 for Visitor Center
26	Owl Creek	Owl Cr. Nr. Lodge Grass, Mont.	96,000		Jan. 1973		17,870,000	Estimated by D&C for N.G.P.R.P.	
27	Arvada	Powder River Nr. Arvada, Wyo.	1,255,000	65,807,000	July 1971	1.29	72,400,000	Missouri-Yellowstone Trib. Report	
28	Hole-in-the-Wall	Middle Fk. Powder Ab. Kaycee, Wyo.	55,000	10,178,000	Oct. 1970	1.22	11,850,000	Mont.-Wyo. Aqueducts Report	

Sheet 2 of 3

Table A-28
COST OF POTENTIAL STORAGE RESERVOIRS
NORTHERN GREAT PLAINS RESOURCE PROGRAM
WORK GROUP (C) WATER

No.	Name of Storage Site	Stream and Location	Approximate Capacity at Maximum Without Surcharge A.F.	Cost From Report	Date of Estimate Prices as of-	Cost Index Jan. 1973	Approximate Cost Jan. 1973 Does Not Include IDC	Source of Cost Information	Alternatives For-or Remarks
29	Moorhead	Powder River Nr. Moorhead, Mont.	1,150,000	80,019,000	Oct. 1970	1.22	98,200,000	Mont.-Wyo. Aqueducts Report	
30	Pumpkin	Powder River	1,000,000	59,000,000	Jan. 1972	1.06	62,600,000	Wyoming Water Plan Report No. 10	
31	Lower Clear Creek	Clear Creek, Wyo.	602,000	35,000,000	Jan. 1972	1.06	37,100,000	Wyoming Water Plan Report No. 10	
32	Lower Crazy Woman	Crazy Woman Creek	480,000	38,000,000	Jan. 1972	1.06	40,300,000	Wyoming Water Plan Report No. 10	
33	Box Elder	Upper Tongue River	54,300	25,800,000	Jan. 1970	1.14	29,460,000	Miss.-Yellowstone Trib.	Does not agree with information from Mont.-Wyo. Aqueducts Report
34	Rockwood	Tongue River, 8 Miles SW, Dayton, Wyo.	113,000	48,500,000	July 1970	1.06	51,000,000	Basic Estimate DC-1 Summary Dated Aug. 17, 1970-No ROW Cost Included	See Power & Gibbs 57,000 A.F. is top of Conservation Pool-Cost Excludes Power Facilities
35	Stateline Res.	Tongue River at Wyo.-Mont. Line	203,600				27,467,000	Report for State of Wyoming	
36	New Tongue	Tongue River at 4-Mile Cr., Mont.	320,000				42,750,000	Bechtel Report	
37	North Prairie Dog	Prairie Dog Creek Nr. Mouth, Wyo.	39,500				17,030,000	Report for State of Wyoming	
38	Mill Iron	Box Elder Cr. Nr. Baker, Mont.	45,000	8,885,000	Jan. 1973		8,885,000	From Wade Stone by Phone. Study Summary, Mill Iron and Reservoir, Sept. 1971	Includes $500,000 for Recreation
39	Medora	Little Missouri Nr. Medora, N.D.	332,000	19,040,000	July 1951	1.80	34,240,000	Unassembled Report 9/5/51 Recon. Investigations on Little Missouri	Ripley, Nuno, Ranger, Reservoirs are alternates. May include surcharge
40	Wagon Creek	Little Missouri	230,000				15,970,000	Memo from Manthy and North Dakota State Water Commission	
41	Marmarth	Little Missouri	334,000		Jan. 1972	1.06	13,830,000	Memo from Manthy and North Dakota State Water Commission	
42	Deep Creek	Little Missouri	75,700				4,300,000	Memo from Manthy and North Dakota State Water Commission	
43	Beaver Creek	Beaver Creek, North Dakota	89,000	5,036,000	Jan. 1972	1.06	5,400,000	Memo from Manthy and North Dakota State Water Commission	
44	Broncho	Knife River, North Dakota	304,000			1.40	11,292,000	Report on Knife Division-June 1965	
45	Emerson	Knife River, North Dakota	80,000				3,517,000	Memo from Manthy and North Dakota State Water Commission	
46	New Yersippi	Heart River	16,000		Jan. 1973		9,000,000	Bob Manthy, Bismarck Office	Lower Site
47	Mott	Cannonball River Nr. Mott	390,000	14,880,000	July 1966	1.48	21,980,000	Status Report on Mott Unit-Jan. 1967	Cost include $503,000 for F.&W.L. & Recreation
48	Cannonball	Cannonball River Nr. Mott	172,000		Jan. 1973		10,536,000	Status Report on Mott Unit-Jan. 1967	
49	Bently	Cannonball, North Dakota	210,000				9,474,000	Aug. 14, 1973, Letter North Dakota State Water Commission	
50	Regent	Cannonball, North Dakota	71,000	8,606,000	Jan. 1972	1.06	9,330,000	Aug. 14, 1973, Letter North Dakota State Water Commission	
51	Hettinger	Cedar River, North Dakota	31,300	5,000,000	Jan. 1972	1.06	5,313,000	Aug. 14, 1973, Letter North Dakota State Water Commission	
52	Thunderhawk	Cedar Creek, North Dakota	216,000	8,019,000	April 1966	1.46	12,376,000	Wrap-up Report-June 1961	Stevens Axis-with Flood Control

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Sheet 3 of 3

Table A-26
COST OF POTENTIAL STORAGE RESERVOIRS
NORTHERN GREAT PLAINS RESOURCE PROGRAM
WORK GROUP III WATER

No.	Name of Storage Site	Stream and Location	Approximate Capacity of Maximum Without Surcharge A.F.	Cost from Report	Date of Estimate Prices as of-	Cost Index Jan. 1973	Approximate Cost Jan. 1973 Does Not Include IDC	Source of Cost Information	Alternatives For-Or Remarks
33	Bixby	Moreau River, South Dakota	370,000	[illegible]	June 1950	1.40	24,830,000	1950 Definite Plan Report Bixby Unit	Top of flood pool 215,000 A.F.
34	Kendall	Green River, Wyoming - (Sweetwater Plan)	495,000	[illegible]	Jan. 1970	1.14	26,150,000	Alternative Plans for Water Resource Developments, Green River Basin - Special Report May 1972	Includes $1,700,000 for irrigation capacity
35	Newcastle	Beaver Creek, Wyoming	13,000	3,000,000	Jan. 1972	1.06	3,200,000	Wyoming Water Plan Report No. 10	Also known as Beaver Creek
36	Lower Green	Green River near Green River, Wyoming	260,000	30,154,000	Jan. 1972	1.06	31,963,000	Wyoming Report on Development of Presently Unused Water Supplies of Green River, October 1972	Based on 450,000 A.F. annual yield. Direct costs from Report recomputed.
37	Clarks Fork	Clarks Fork-Yellowstone River, Wyoming	815,000	--	Jan. 1973	--	75,000,000	Independent Estimate	--

TABLE A-30
COST SUMMARY
NORTHERN GREAT PLAINS RESOURCE PROGRAM
EXTENSIVE DEVELOPMENT - ALTERNATIVE 4
GREEN RIVER TO GILLETTE AREA TRANSPOSED

Aqueduct and Reach	Length (Miles)	AF/Yr. (1000's)	Q (Ft.^{3}/s)	Pipe Size Inches (Nominal)	Total Static Head (Feet)	Total Dynamic Head (Feet)	Total Field Cost (Jan-75) ($1000's)	Int. During Construction 2/ (4 years) ($1000's)	Administration and General Expense (20%) ($1000's)	Total Project Investment ($1000's)	Annual Capital Repayment 3/ ($1000's)	OM&R ($1000's)	Annual Pumping Cost 4/ ($1000's)	Total Annual Cost ($1000's)	Total Annual Cost/AF (Per Reach)	Total Annual Cost (Per AF) 5/
North Platte to G-1 1/	67.42	289.5	411	96	450	516	$129,240	$24,540	$21,550	$174,333	$14,620	$322	$1,660	$16,602	$57.30	$201.30
G-1 to G-2	3.60	199.3	286	66	30	40	8,000	1,535	1,600	11,135	935	50	177	1,162	5.80	207.10
G-2 to G-3	6.66	169.2	243	66	90	128	13,125	2,520	2,625	18,270	1,332	41	240	1,613	10.70	217.80
G-3 to G-4	9.00	139.5	200	78	140	194	14,400	2,765	2,880	20,045	1,680	37	300	2,017	14.30	232.10
G-4 to G-5&6	6.91	78.5	114	48	0	0	5,925	1,140	1,185	8,250	690	12	0	702	8.40	241.10
G-5&6 to P-1	10.23	19.5	28	39	0	0	4,390	845	880	6,115	515	15	0	530	27.20	268.30
G-1 to G-7	13.54	60.0	84	60	250	310	12,310	2,365	2,460	17,135	1,420	49	215	1,684	28.20	229.50
G-7 to G-8	6.34	30.0	43	39	150	217	4,370	840	875	6,085	510	23	72	605	20.20	249.70
G-4 to G-9	4.79	30.0	43	33	0	0	2,990	575	600	4,165	350	8	0	358	11.90	244.20

1/ Aqueduct originates on North Platte River directly upstream of Douglas, Wyoming. It then parallels Hwy. 59 to Bill, Wyoming, thence NE to mouth of South Fork Cheyenne River, thence NE to G-1.
2/ Interest during construction computed @ 8% interest rate over 4-year construction period.
3/ Investment amortized over 40 years @ 8%.
4/ Power cost computed @ 8 mills/kwh.
5/ Basic water charge from North Platte River based on $144/A.F. of water transported from Lower Green River Reservoir.

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Table A-31

COST SUMMARY AND QUANTITY
Water Transmission and Storage at Plants
Extensive Development-Alternative 4-Green River to Gillette
Area Transposed

Northern Great Plains Resource Program
Work Group (C) Water

Source of Water	Delivery Point	Quantity Delivered AF/yr.	Total Cost Per AF (Jan. 1973)
Green River	Near Douglas	293,000	141.00
North Platte	P-1	23,000	268.00
North Platte	G-1	30,000	201.00
North Platte	G-2	30,000	207.00
North Platte	G-3	30,000	218.00
North Platte	G-4	30,000	232.00
North Platte	G-5	30,000	241.00
North Platte	G-6	30,000	241.00
North Platte	G-7	30,000	230.00
North Platte	G-8	30,000	250.00
North Platte	G-9	30,000	244.00

Water Transmission Costs with Various Interest Rates and Amortization Periods

Northern Great Plains Resource Program
Work Group (C) Water

Lake Sakakawea to Cave Hills

Aqueduct Capacity - 300 cfs - 208,000 AF/yr
Pumping Power Rate - 6 mills/Kwhr
For each mill increase - add $3.00/AF

Amortization Period
30 years – – – – –
40 years —— · ——
50 years ————

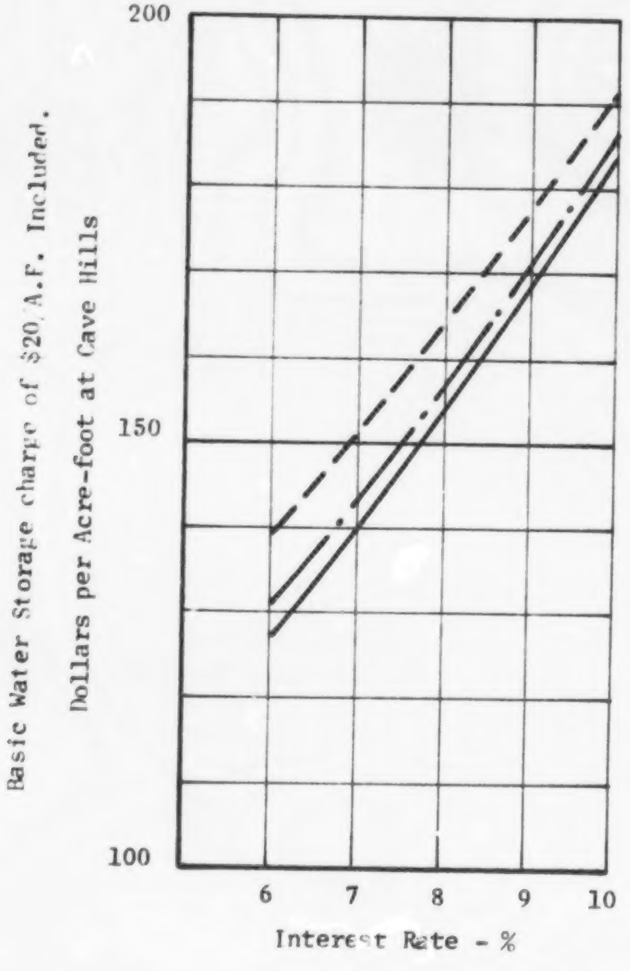

Figure A-1

Water Transmission Costs with Various Interest Rates and Amortization Periods

Northern Great Plains Resource Program
Work Group (C) Water

Lake Oahe to Gillette

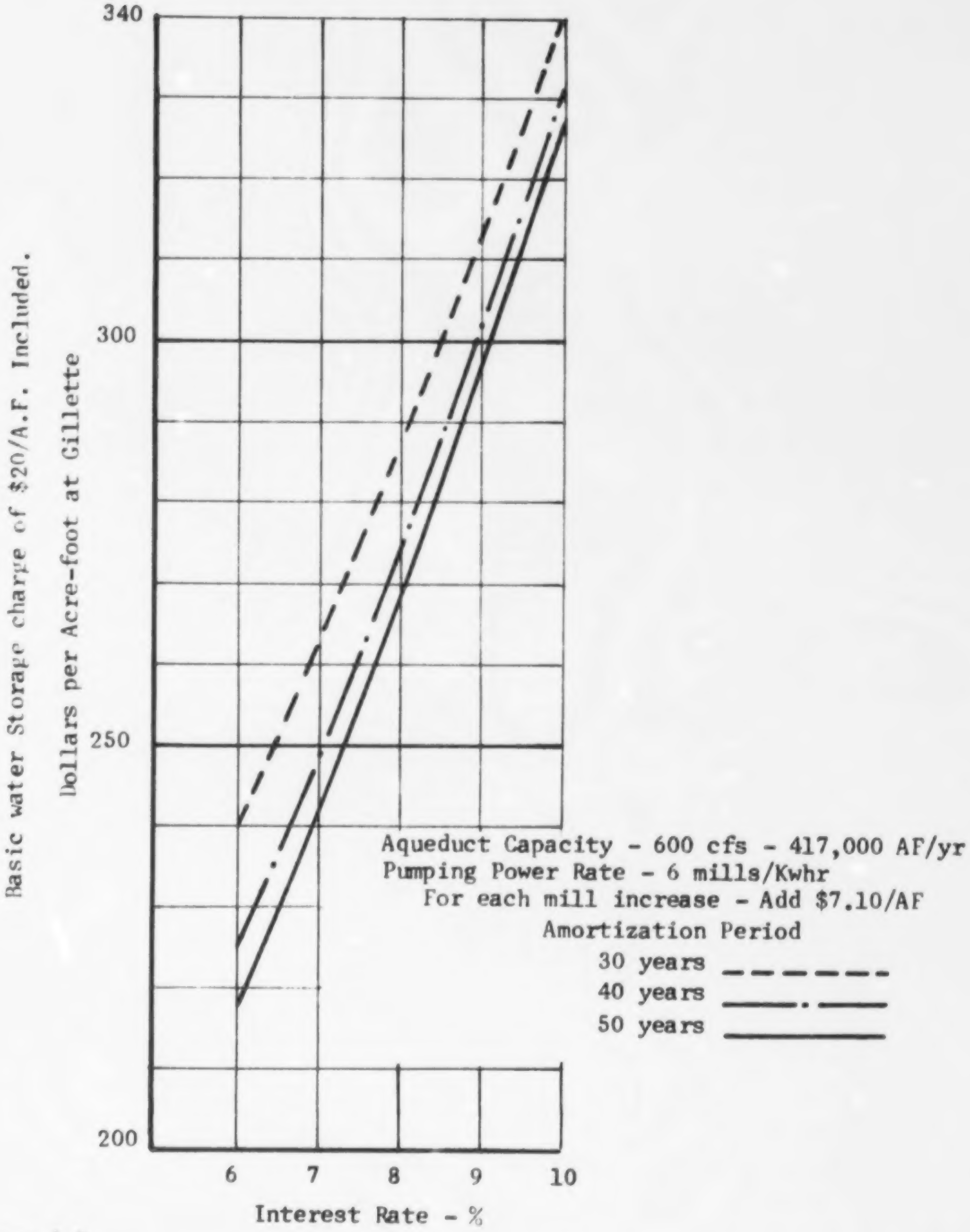

Figure A-2

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Water Transmission Costs with Various Interest Rates and Amortization Periods

Northern Great Plains Resource Program
Work Group (C) Water

Miles City to Gillette

Aqueduct Capacity - 1000 cfs - 694,000 AF/yr
Pumping Power Rate - 6 mills/Kwhr
For each mill increase - add $4.40/AF

Amortization Period
30 years — — — — —
40 years ——— · ———
50 years ——————

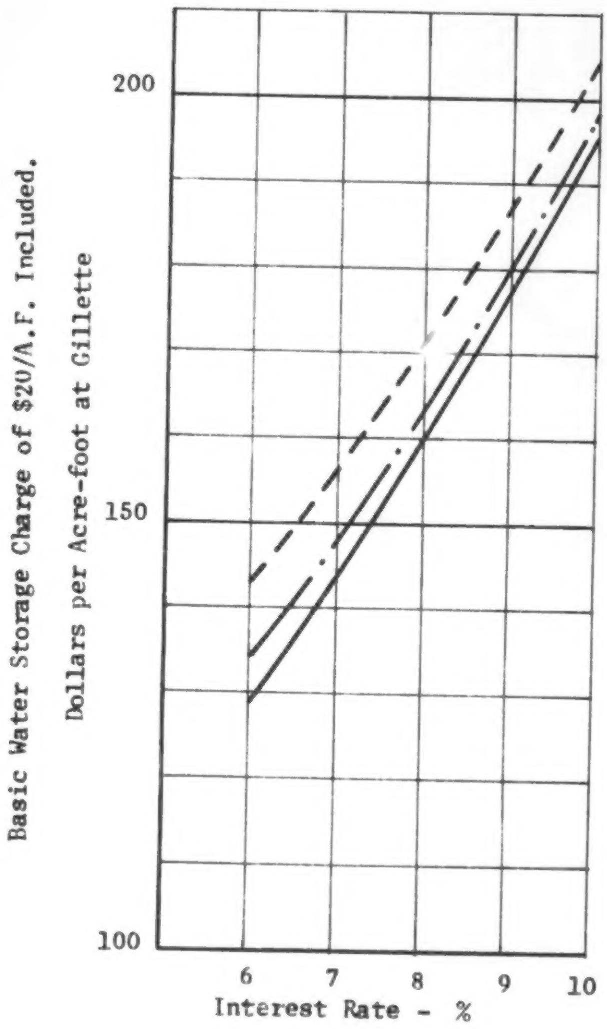

Figure A-3

Water Transmission Costs
Lake Sakakawea to Cave Hills, South Dakota
Northern Great Plains Resource Program
Work Group (C) Water

Interest Rate @ 8%
Amortization Period over 40 Years
Electrical Power @ 8 mills/Kwhr

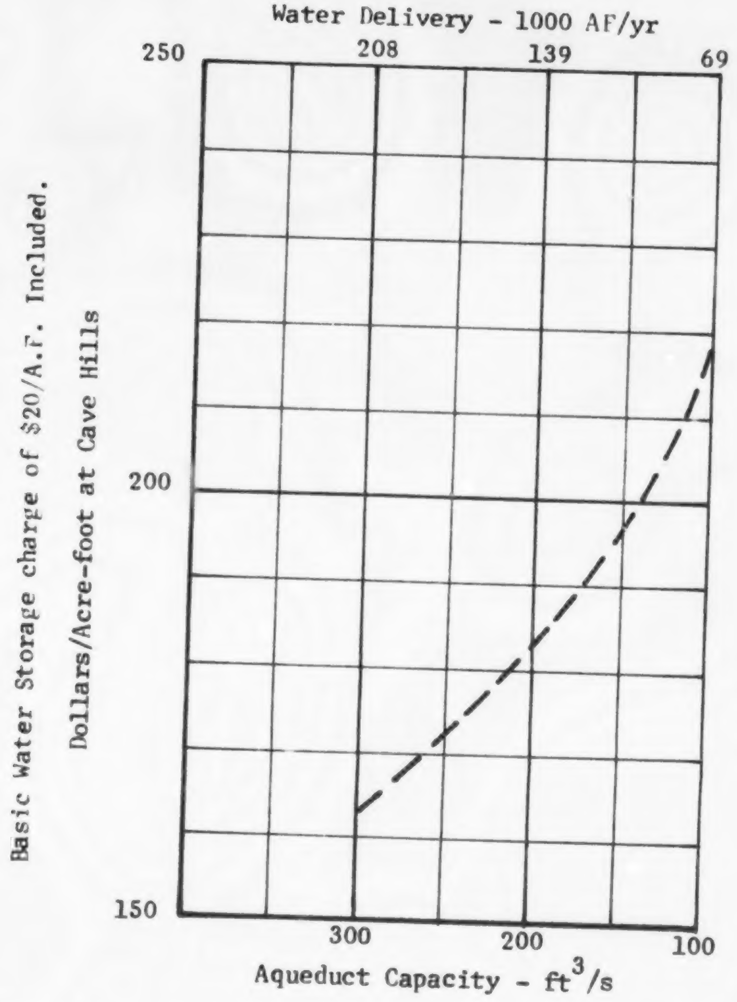

Figure A-4

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Water Transmission Costs
Lake Oahe to Gillette
Northern Great Plains Resource Program
Work Group (C) Water

Interest Rate @ 8%
Amortization Period over 40 years
Electrical Power @ 8 mills/Kwhr

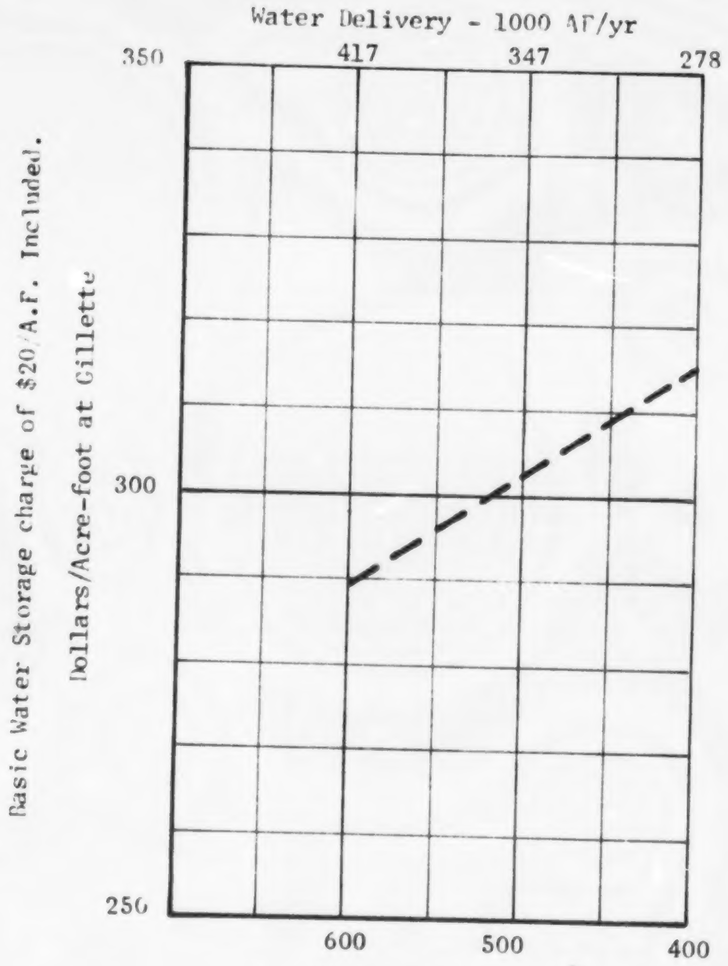

Figure A-5

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Water Transmission Costs
Miles City to Gillette
Northern Great Plains Resource Program
Work Group (C) Water

Interest Rate @ 8%
Amortization Period over 40 Years
Electrical Power @ 8 mills/Kwhr

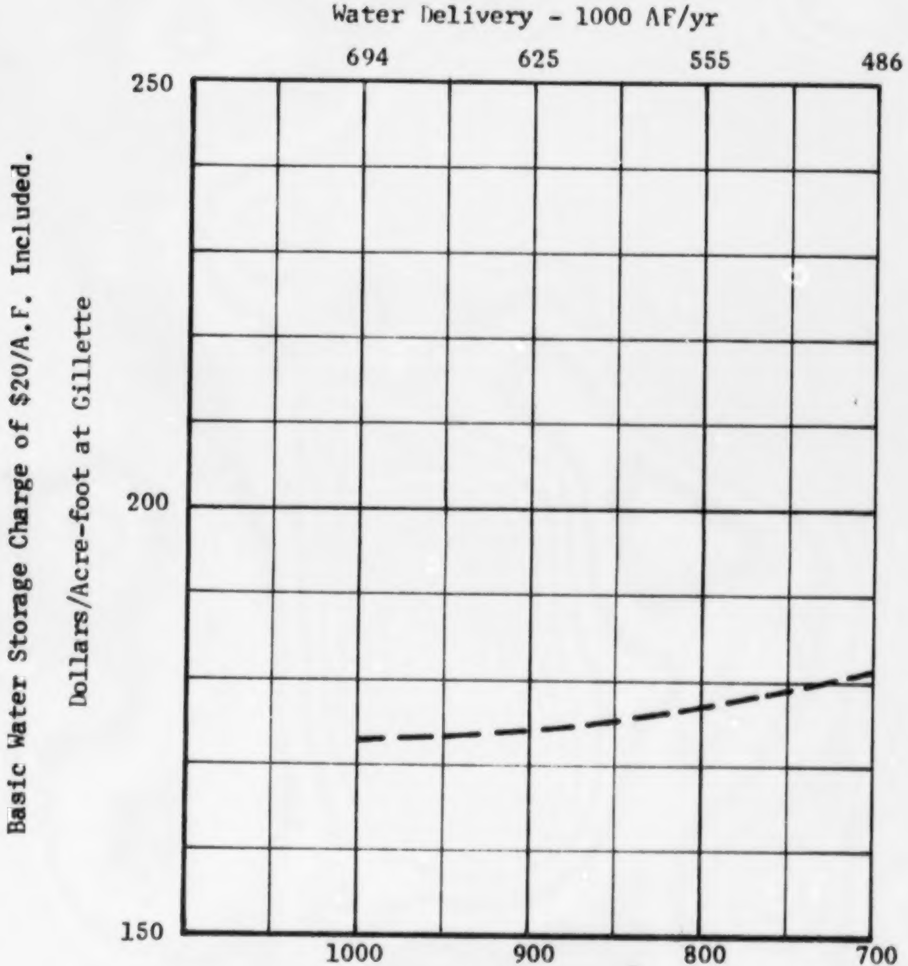

Figure A-6

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Water Availability Appendix

WATER SUPPLY ANALYSES

GENERAL PROCEDURE AND CRITERIA

Water Supply studies were conducted on Bureau of Reclamation computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This computer program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The model also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

All water supply studies were conducted with runoff figures which reflect the 1970 level of water resource development above each stream point. For studies of water supply in the Bighorn River Basin, the 1970 level runoff was adjusted to remove the effects of the existing Boysen and Bighorn Reservoirs. This adjustment was needed to prevent a double reservoir operation on the Bighorn River system.

Previous Bureau of Reclamation studies conducted for the Bighorn River (using storage in Bighorn Reservoir) indicated that about 1.22 million acre-feet of water could be developed annually for industrial uses. Thus, for comparative purposes, two separate sets of studies were conducted for the Yellowstone River (with mainstream and offstream storage) and Clarks Fork Yellowstone River. The first set of studies used the 1970 level runoff which did not include any diversion of water from the Bighorn River. The second set of studies used an annual diversion of 1.22 million acre-feet of water from the Bighorn River on a constant flow basis.

In most of these water supply studies, full instream water needs criteria (as determined by the Bureau of Sport Fisheries Wildlife) were used. These criteria include:

1. Monthly instream needs at various stream points.
2. Runoff in excess of instream needs could be stored or diverted.
3. When runoff drops below instream needs, water could not be stored or diverted.
4. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs but these releases were not considered a project function.

The only exceptions to the use of full instream water needs were as follows:

1. Studies were conducted on the Bighorn River to determine the effects on the instream water needs for the First Choice, Extensive Development scenario. This choice called for a diversion of 1,151 cubic-feet-per-second at Hardin, and only 55 percent of the instream needs could be met during the critical period. Results of this study do not appear on Tables 5a-5d in the main report.

2. For comparative purposes only, most water supply studies were repeated with the instream water needs reduced to 10 percent of the recommended values.

In most water supply studies, new irrigation was not considered. The exceptions were: 1) 5,000 acres from Broncho Reservoir on the Knife River, and 2) 59,000 acres in the Wind River, 50,000 acres in the Wind Indian Reservation for future use, and 9,000 acres on Cottonwood Bench now being developed. Although the water supply studies were designed primarily to show the amount of water that could be depended upon (without shortages) for diversion for industrial purposes, these studies actually indicate the total amount of water available for diversion for all uses.

Industrial diversions were provided at a constant rate throughout the year. No shortages were allowed for these diversions.

Reservoir area-capacity curves were obtained by the Work Group from old Bureau of Reclamation reports and from the States of Montana, Wyoming, and North and South Dakota.

Irrigation diversion and return flow schedules used, as well as reservoir evaporation schedules, were obtained from various Bureau of Reclamation studies.

Reservoir capacities were obtained from a table prepared by the Water Work Group listing potential storage sites in the Yellowstone and Western Dakota stream basins. The data in this table were obtained from old Bureau of Reclamation reports, the States of Montana, Wyoming, North Dakota, and South Dakota, and from limited field reconnaissance studies. The only exception was for Allenspur Reservoir for which definite monthly flood control space information was available.

All water supplies studies utilized a type of reservoir operation in which water in excess of downstream needs, including instream water needs, would be stored in the reservoir for later release for project needs. When the reservoir was filled to its maximum allowable capacity, the excess water would be passed directly through the reservoir and released downstream. For all reservoirs, except Allenspur Reservoir, the maximum allowable capacity was held constant throughout the individual study. In all studies in which Allenspur Reservoir was part of the stream system, the maximum allowable contents varied by month in order to allow for flood control operation.

The remainder of this appendix consists of excerpts from Memoranda regarding the water supply studies. Because of bulk, some tables, figures, etc. referred to in the Memoranda are not contained in this appendix. The complete Memoranda are on file in the Planning Division, Upper Missouri Regional Office, Bureau of Reclamation, Billings, Montana.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: March 19, 1974

FROM : David M. Haisten, Hydraulic Engineer

SUBJECT: Water Supply Analysis, Yellowstone River Basin, Allenspur Reservoir and Offstream Storage only, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water in the Yellowstone River for industrial and other purposes.

The Yellowstone River rises in northwestern Wyoming and passes through Yellowstone National Park. From the park it flows in a northern direction to Livingston, Montana, thence easterly to Billings and northeasterly to Sidney, joining the Missouri River a few miles east of the Montana-North Dakota State line. Drainage area is about 70,115 square miles. Major tributaries include the Stillwater, Boulder, Clarks Fork Yellowstone, Bighorn, Tongue, and Powder Rivers. A map of the Yellowstone River Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream needs criteria. The model also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

All water studies were conducted with runoff figures which reflect the 1970 level of water resources development in the basin.

The various data used in the program are shown below with a short discussion as to source, estimates, and assumptions.

1. Instream water needs: Memorandum dated December 27, 1973, To: Phil Gibbs, Water Work Group Leader, NGPRP, Bureau of Reclamation, From: Acting Area Manager, Bureau of Sport Fisheries and Wildlife, Subject: Northern Great Plains Resource Program -

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

Estimates of Instream Water Needs for the Clarks Fork, Little Bighorn, Bighorn (below Yellowtail Reservoir) and Yellowstone Rivers. A copy of this memorandum is not attached, but Table 1 summarizes the instream needs. The point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2. All runoff data reflect the 1970 level of development. Stream points used are:

   A. Yellowstone River near Livingston (Allenspur Damsite): The recorded runoff at this gaging station was adjusted to the 1970 level of development in the MRB 1/ framework study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB framework study.

   B. Yellowstone River above Boulder River: Runoff was estimated as the drainage area ratio of the incremental runoff (1970 level) between the gaging stations Yellowstone River at Billings, Yellowstone River near Livingston, Stillwater River near Absarokee, and Clarks Fork Yellowstone River at Edgar, plus the runoff of Yellowstone River near Livingston. This runoff was then applied to runoff at the Livingston gage resulting in a factor of 1.111 times the runoff at the Livingston gage (Figure 3).

   C. Yellowstone River above Stillwater River: The runoff at this location was estimated in the same manner as for Yellowstone River above Boulder River (Figure 3). The factor thus derived was 1.253.

   D. Yellowstone River above Clarks Fork: The runoff at this location was estimated as the sum of the MRB framework study runoff of Yellowstone River near Livingston and Stillwater River near Absarokee plus 0.776 times the incremental runoff between the MRB runoff points used in determining the runoff for the Yellowstone River above Boulder River (Figure 4).

   E. Yellowstone River above Bighorn River: Runoff was estimated as 1.022 times the 1970 level runoff of Yellowstone River at Billings (Figure 5). The recorded runoff at the Billings gage was adjusted to the 1970 level of development in the MRB framework study through September 1963 and extended in the same manner through September 1970.

1/ Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

F. Yellowstone River above Tongue River (offstream storage): Runoff was estimated as Yellowstone River at Miles City minus Tongue River at Miles City. This location was used in the various studies as the diversion site for all offstream storage.

G. Tongue River at Miles City: The recorded runoff at this gaging station was adjusted to the 1970 level of development in the MRB framework study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB framework study.

H. Yellowstone River at Miles City: The recorded runoff at this gaging station was adjusted to the 1970 level of development in the MRB study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB framework study.

I. Yellowstone River above Lower Yellowstone River: Runoff was estimated by taking the MRB runoff for Yellowstone River near Sidney and adding the combined effects of USBR projects in the reach between Miles City and Sidney. These effects are continued in the supporting material for the MRB framework study.

J. Yellowstone River near Sidney: The recorded runoff at this gaging station was adjusted to the 1970 level of development in the MRB framework study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB study, to obtain 32 years of runoff data.

K. Yellowstone River at Mouth: Runoff was assumed to be the same as for Yellowstone River near Sidney.

3. Area-capacity curves for the various reservoir sites are shown on Figures 6 through 13.

4. The evaporation rate for Allenspur Reservoir was obtained from the October 1963 Yellowstone Division report, 1.80 feet per year. For the offstream reservoir sites the annual evaporation rate of 3.10 feet was obtained from supporting material for the Montana-Wyoming Aqueduct Study (1972).

5. Water years 1938 through 1970 were used as the study period for Allenspur Reservoir. For the offstream reservoir sites, the study period was the water years 1939 through 1970.

These periods represent the longest periods of runoff records available for all stations used. Studies for the offstream reservoirs are shorter by 1 year because of the need to use Tongue River at Miles City for computing runoff at the offstream storage diversion point.

6. Reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Minimum contents for the offstream sites were assumed to be zero.

Reservoir	Maximum (Acre-feet)	Active (Acre-feet)	Minimum (Acre-feet)
Allenspur	4,000,000 1/	1,830,000	2,120,000
Sunday Creek	678,000	678,000	0
Tullock Creek	270,000	270,000	0
Moon Creek	150,000	150,000	0
Cedar Ridge	126,800	126,800	0
Sweeney Creek	116,000	116,000	0
Buffalo Creek	72,700	72,700	0
Lignite Creek	30,000	30,000	0

1/ Includes 50,000 acre-feet exclusive flood control space.

7. Flood control was considered only for Allenspur Reservoir. The flood control schedule was obtained from letters dated January 11, 1962, from the USBR, Billings Regional Office to U.S. Army Engineer District Office in Omaha, Nebraska, and April 10, 1962, from the District Office in reply. The resulting storage space required and maximum end-of-month contents used are shown below:

Month	EOM Storage Required (1,000 AF)	Maximum EOM Content 1/ (1,000 AF)
October	217	3,783
November	343	3,657
December	428	3,572
January	514	3,486
February	600	3,400
March	425	3,575
April	250	3,750
May	150	3,850
June	50	3,950
July	50	3,950
August	50	3,950
September	50	3,950

1/ Based on a 4,000,000 acre-foot reservoir.

8. Study criteria:

   a. Water in excess of instream needs could be stored or diverted.

   b. When runoff drops below instream needs, water could not be stored or diverted.

   c. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but these releases were not considered a project function.

   d. Industrial diversions were provided at a constant rate throughout the year. In all studies the industrial diversions were assumed to occur at Miles City.

   e. No shortages were allowed for industrial diversions.

   f. No new irrigation.

Investigation of the other possible main-stem reservoir sites (Absaroka, Lissa, and Wanigan) as well as the effects of new irrigation will be investigated in a future study as time permits.

Previous studies conducted for the Bighorn River (using storage in Yellowtail Reservoir and considering industrial water options for its water) indicated that about 1.22 million acre-feet of water could be developed annually for industrial uses. To reflect this withdrawal of water from the Bighorn River, two separate sets of studies were conducted.

The first set of studies considered no diversion of water from the Bighorn River.

In the second set of studies, 1.22 million acre-feet of water were diverted from the Bighorn River on a constant flow rate basis. When Allenspur Reservoir was operated under the above constraint, the 1.22 million acre-feet were diverted from the Bighorn River as a "water right." This assumption was used in order to show the industrial water coming only from Allenspur Reservoir. When the offstream storage sites were studied under the above constraint, the 1.22 million acre-feet were deducted at a constant flow rate from the 1970 level runoff for the Yellowstone River main-stem control points at and below Miles City.

It should be noted that the 1.22 million acre-feet of water discussed above did not consider the instream water needs in the Bighorn River as

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determined by the BSFW in their December 27, 1973, memorandum. Determination of the availability of water in the Bighorn River Basin, considering BSFW's instream water needs, will be the subject of a future memorandum report. A combination study should also be conducted as time permits.

The results of these studies indicate the total quantity of water available for diversion for all possible uses. More detailed studies concerning other possible uses (municipal, agricultural, etc.) would be required to determine the amount of water available for each use. However, the total water available for all uses is not expected to differ significantly from the results presented in this memorandum.

RESULTS

One study was conducted on the main stem Yellowstone River without any reservoirs or diversions. This study shows the shortages of runoff as compared to the BSFW instream water needs criteria. Summaries of these shortages are shown by stream point on Tables 2 through 10.

Several water supply studies were conducted to determine the maximum possible diversion for industrial uses. The first study in each study set was for Allenspur only. The other seven studies in each study set were for the offstream storage. For ease in conducting these studies the reservoirs were lumped together in a composite reservoir: the first study being the largest offstream reservoir (Sunday Creek); the next study by adding on the next largest reservoir (Tullock Creek), etc.

The results of these studies are shown below:

Study	Diversion (Acre-feet)	Reservoir	Minimum Contents Observed (Acre-feet)	Smallest Surplus 1/ (Acre-feet)	Date 2/
(No diversion from Bighorn River)					
1	1,483,000	Allenspur	2,112,860 3/	0	May 1941
A	957,000	Sunday Creek	930	930	May 1961
B	1,243,000	A+Tullock Creek	190	190	May 1961
C	1,330,000	B+Moon Creek	450	450	Feb 1941
D	1,401,000	C+Cedar Ridge	360	360	Feb 1941
E	1,466,000	D+Sweeney Creek	280	280	Feb 1941
F	1,507,000	E+Buffalo Creek	0	0	May 1941
G	1,520,000	F+Lignite Creek	0	0	May 1941

(Diversion from Bighorn River - 1.22 million A.F.)

1Y	400,000	Allenspur	2,119,600 3/	0	April 1941
AY	710,000	Sunday Creek	530	530	May 1961
BY	915,000	AY+Tullock Creek	350	350	May 1941
CY	988,000	BY+Moon Creek	910	910	May 1941
DY	1,049,000	CY+Cedar Ridge	1,490	1,490	May 1941
EY	1,106,000	DY+Sweeney Creek	0	0	Jan 1962
FY	1,119,000	EY+Buffalo Creek	1,360	1,360	Jan 1962
GY	1,130,000	FY+Lignite Creek	1,300	1,300	Jan 1962

1/ Minimum content observed less minimum allowable content.
2/ For study period.
3/ Minimum contents observed are less than the minimum allowable contents (2,120,000 acre-feet) because of evaporation losses only. No shortage to diversion or increase of shortage to instream needs criteria.

Annual summaries for each of these studies are included in this memorandum. A column explanation for the summaries is included just prior to the summaries.

Again, the results indicate the total quantity of water available for all uses.

Below is an index of the summary tables for each study:

Study	Diversion from Bighorn River 0 AF	 1.22 million AF
1	11-20	98-107
A	21-31	108-118
B	32-42	119-129
C	43-53	130-140
D	54-64	141-151
E	65-75	152-162
F	76-86	163-173
G	87-97	174-184

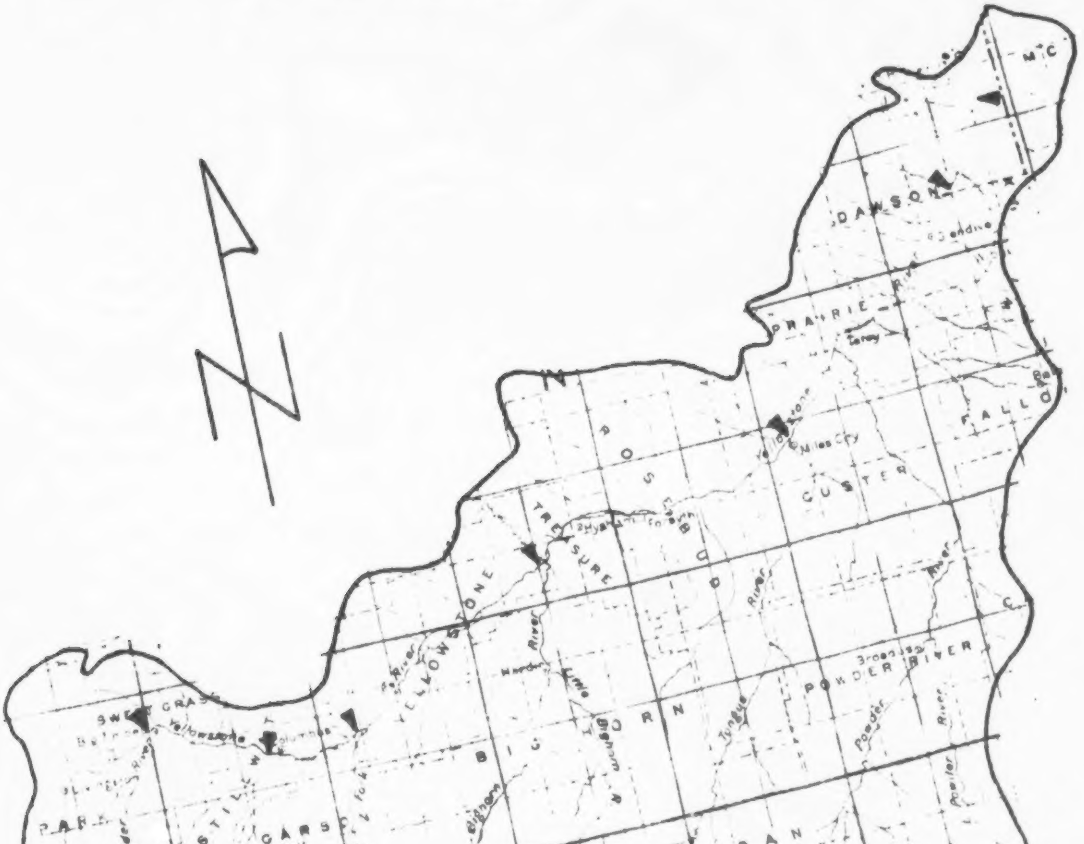
CONCLUSION

Without any diversion from the Bighorn River, about 1.483 million acre-feet of water could be developed annually for industrial uses from Allenspur Reservoir and still meet BSFW's instream water needs criteria. Up to 1.52 million acre-feet annually could be developed for diversion from offstream storage. Assuming 1.22 million acre-feet diversion from the Bighorn River, Allenspur Reservoir could develop 400,000 acre-feet annually while offstream storage could develop up to 1.13 million acre-feet annually for industrial uses.

David M. Hanston

I concur: John W. Keys III
Regional Hydrologist

YELLOWSTONE RIVER BASIN


N
DAWSON
PRAIRIE
FALLON
CUSTER
Miles City
Yellowstone
ROSEBUD
TREASURE
YELLOWSTONE
BIG HORN
POWDER RIVER
Broadus
Tongue River
Powder River
SWEET GRASS
Big Timber
Columbus
STILLWATER
CARBON
Red Lodge
PARK
Boulder
Bighorn River
Hardin
Little Bighorn R
SHERIDAN
Sheridan
BIG HORN
PARK
Cody
Greybull River
Shoshone
Yellowstone Lake
JOHNSON
Buffalo
WASHAKIE
Worland
HOT SPRINGS
Nowood Creek
FREMONT
Lander
WYOMING

▲ Point of instream water need

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Figure 1

Table 1 - Instream Water Needs, Yellowstone River 1/
(CFS)

Stream Point	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Above Boulder River	1,190	1,200	1,260	1,540	4,000	4,000	4,000	3,200	2,100	1,950	1,680	1,400
Above Stillwater River	1,335	1,335	1,385	1,700	4,600	4,600	4,600	3,390	2,300	2,300	1,870	1,565
Above Clarks Fork	1,600	1,600	1,750	2,000	5,500	5,500	5,500	4,200	2,900	2,800	2,300	1,900
Above Bighorn River	1,950	1,950	2,100	2,350	7,500	7,500	7,500	3,600	3,200	3,100	2,650	2,250
At Miles City	3,500	3,500	4,200	4,400	10,000	10,000	10,000	5,000	5,000	5,000	4,700	4,400
Above Lower Yellowstone Canal	3,600	3,600	4,400	4,600	10,500	10,500	10,500	5,100	5,100	5,100	4,800	4,500
Above Sidney	3,500	3,500	4,400	4,600	10,500	10,500	10,500	4,000	4,000	4,000	4,000	4,000
At Mouth	3,400	3,500	4,400	4,600	12,000	12,000	12,000	4,000	4,000	4,000	4,000	4,000

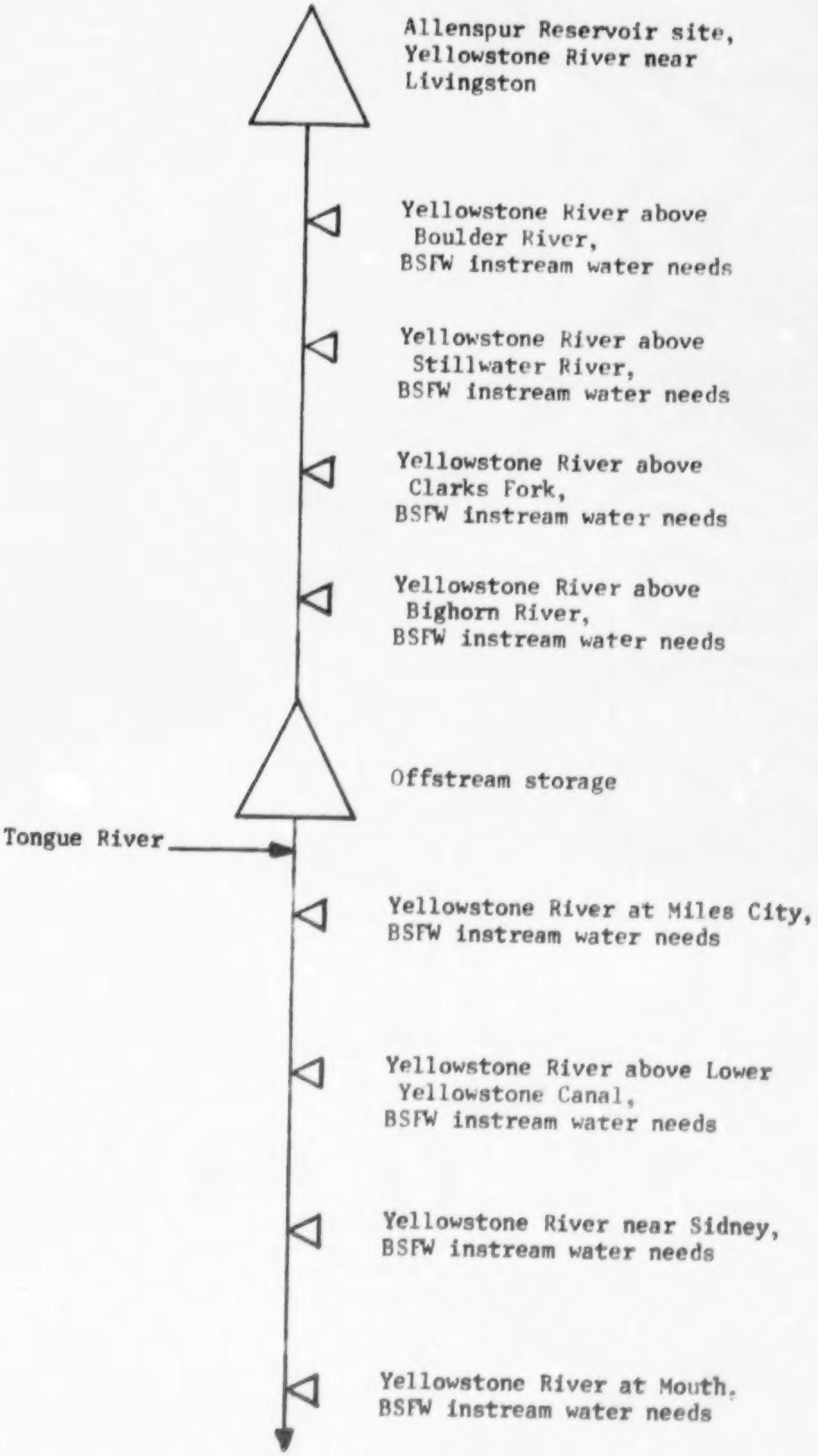
Allenspur Reservoir site, Yellowstone River near Livingston
Yellowstone River above Boulder River, BSFW instream water needs
Yellowstone River above Stillwater River, BSFW instream water needs
Yellowstone River above Clarks Fork, BSFW instream water needs
Yellowstone River above Bighorn River, BSFW instream water needs
Offstream storage
Tongue River
Yellowstone River at Miles City, BSFW instream water needs
Yellowstone River above Lower Yellowstone Canal, BSFW instream water needs
Yellowstone River near Sidney, BSFW instream water needs
Yellowstone River at Mouth, BSFW instream water needs

Figure 2

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist **DATE:** June 20, 1974

FROM : David M. Haisten, Hydraulic Engineer

SUBJECT: Water Supply Analysis, Clarks Fork Yellowstone River Basin, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water in the Clarks Fork Yellowstone River Basin and the quantity available for diversion for industrial purposes.

The Clarks Fork Yellowstone River rises in the Beartooth Mountains of southern Montana and flows south into Wyoming. The Clarks Fork then flows east through Wyoming and then north back into Montana, finally joining the Yellowstone River a few miles west of Billings near Laurel. The basin is about 60 miles wide at the Wyoming-Montana boundary and 90 miles long, with a drainage area of 2,783 square miles. The major water producing area lies in the mountains of Shoshone and Custer national forests. Major tributaries in Wyoming include Crandall, Sunlight, Dead Indian, Pat O'Hara, and Big Sandy creeks. In Montana, Rock Creek is the largest tributary. A map showing the Clarks Fork Drainage Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The program also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

Water supply studies included points on the Yellowstone River because of the possible diversion of industrial water from the river at Miles City and estimates of instream water requirements in the Yellowstone River. Since previous studies (not NGPRP) conducted for the Bighorn River using storage in Bighorn Lake indicated that about 1.22 million acre-feet of water could be developed annually for industrial purposes, two sets of studies were conducted. The first set of studies considered no diversion of water from the Bighorn River. In the second set of studies the 1.22 million acre-feet were deducted at a constant flow rate from the 1970 level runoff for the Yellowstone River main-stem control points at and below Miles City.

It should be noted that the 1.22 million acre-feet of water discussed above did not consider the instream water needs in the Bighorn River as determined

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by the BSFW for the NGPRP studies. Determination of the availability of water in the Bighorn River Basin, considering BSFW's instream water needs, will be the subject of another memorandum report. All water studies were conducted with runoff figures which reflect the 1970 level of water resources development in the basin.

The various data used in the program are shown below with a short discussion as to source, estimates and assumptions.

1. Instream water needs: Memorandum dated December 27, 1973, To: Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings Montana, From: Area Manager, Bureau of Sport Fisheries and Wildlife, Subject: Northern Great Plains Resource Program--Estimates of Instream Water Needs for the Clarks Fork, Little Bighorn (below Yellowtail Reservoir) and Yellowstone Rivers. A copy of this memorandum is not attached, but Table 1 summarizes the instream water needs used in this study. The point of each instream need in the Clarks Fork Basin is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies and were applied to the upper end of the stream reach where designated.

2. Stream point locations for runoff are shown schematically on Figure 2. All runoff data reflect the 1970 level of development.

   A. Clarks Fork at Pilot Creek: Runoff was estimated as the drainage area ratio (80/194 = 0.412) times the runoff of Clarks Fork above Squaw Creek (item 2.C.).

   B. Clarks Fork at Hunter Mountain Damsite: Runoff was estimated as the drainage area ratio (163/194 = 0.840) times the runoff of Clarks Fork above Squaw Creek (item 2.C.).

   C. Clarks Fork above Squaw Creek: Runoff for the water years 1928 through 1953 was obtained from the 1957 Bureau of Reclamation report on the Clarks Fork Division. From 1954 through 1970, runoff was estimated: the months of April through November were estimated by a correlation with the station Clarks Fork near Belfry (Figure 3); the months December through March were estimated in the same manner as used in the 1957 Division Report.

   D. Clarks Fork above Crandall Creek: Runoff was estimated as the drainage area ratio (258/194 = 1.330) times the runoff of Clarks Fork above Squaw Creek.

   E. Clarks Fork at Thief Creek Damsite: Runoff through 1953 was obtained from Table 4 of the 1957 Division Report and extended through 1970 by the same method as used in the Division Report.

F. Sunlight Creek near Painter: Runoff through 1953 was obtained from Table 1 of the 1957 Division Report and extended through 1970 by using recorded runoff for this station.

G. Sunlight Creek at Sunlight Damsite: Runoff was assumed to be the same as recorded for Sunlight Creek near Painter.

H. Clarks Fork above Dead Indian Creek: Runoff was estimated as the sum of Clarks Fork above Sunlight Creek (estimated as the drainage area ratio of 513/476 = 1.078 times Clarks Fork at Thief Creek Damsite) and Sunlight Creek at mouth (estimated as the drainage area ratio of 158/135 = 1.170 times Sunlight Creek near Painter).

I. Dead Indian Creek at Mouth: Runoff was estimated as the drainage area ratio (57/135 = 0.422) times Sunlight Creek near Painter.

J. Clarks Fork below Dead Indian Creek: Runoff was assumed to be the same as Clarks Fork at Baldridge Reservoir (item 2.K.).

K. Clarks Fork at Baldridge Damsite: Runoff through 1953 was obtained from Table 5 of the Division report and extended through 1970 by the same method.

L. Clarks Fork above Pat O'Hara Creek: Runoff was estimated as the drainage area ratio (813/735 = 1.106) times Clarks Fork at Baldridge Damsite.

M. Clarks Fork at Belfry: Runoff was estimated as the incremental drainage area ratio (1,418-813)/(2,032-813) = 0.496) times the runoff between the stream points at Edgar (item 2.O.). and above Pat O'Hara Creek, plus above Pat O'Hara Creek.

N. Clarks Fork at Bridger: Runoff was estimated as the incremental drainage area ratio (1,867-813)/(2,032-813) = 0.865) times the runoff between the stream points at Edgar (item 2.O.).and above Pat O'Hara Creek, plus above Pat O'Hara Creek.

O. Clarks Fork at Edgar: Recorded runoff at this station was adjusted to the 1970 level development in the MRB[1] study through September 1963. Recorded runoff through 1970 was adjusted in the same manner.

P. Clarks Fork at Mouth: Runoff was estimated to be 1.355 times the runoff at Clarks Fork at Edgar. Derivation of this factor is shown on Figure 4.

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[1] Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966

   Q. Yellowstone River at Miles City: Runoff at this point is the same as used in the Yellowstone study.[2]

   R. Yellowstone River at Mouth: Runoff at this point is the same as used in the Yellowstone study.[2]

3. Area-capacity curves for the various reservoir sites investigated were obtained from the 1957 Clarks Fork Division Report (Figures 5, 6, 7 and 8).

4. Reservoir evaporation rate of 2.66 acre-feet per acre was obtained from the 1957 Clarks Fork Division Report.

5. Water years 1939 through 1970 were used as the study period since these years represent the longest period of runoff records available for all stations used. These records were adjusted to show the 1970 level of development within the basin.

6. Reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Reservoir capacities used are as follows:

Reservoir	Maximum (acre-feet)	Active (acre-feet)	Minimum (acre-feet)
Thief Creek	200,000	190,000	10,000
Hunter Mountain	130,000	127,000	3,000
Sunlight	50,000	48,000	2,000
Baldridge	14,600	10,200	4,400

7. Flood control was not considered for this study.

8. Study criteria:

   A. Water in excess of instream needs could be stored or diverted.

   B. When runoff drops below instream needs, water could not be stored or diverted.

   C. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but these releases were not considered a project function.

   D. Industrial diversion was assumed to occur at Miles City.

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[2] Memorandum report dated March 19, 1974, subject: Water Supply Analysis, Yellowstone River Basin, Allenspur Reservoir and Offstream Storage only, Northern Great Plains Resource Program.

E. Industrial diversions were provided at a constant rate throughout the year.

F. No shortages were allowed for industrial diversions.

G. No new irrigation.

The results of these studies indicate that total quantity of water available for diversion for all possible uses. More detailed studies concerning other possible uses (municipal, agricultural, etc.) would be required to determine the amount of water available for each use. However, the total water available for all uses is not expected to differ significantly from the results presented in this memorandum.

RESULTS

One study was conducted without any reservoirs or diversions. This study shows the shortages of runoff as compared to the BSFW instream water needs criteria. Summaries of these shortages are shown by stream point on Tables 2 through 13.

Results of the various studies are shown below:

Study	Reservoir	Diversion (acre-feet)	Minimum Contents Observed (acre-feet)	Smallest Surplus 1/ (acre-feet)	Date 2/
(No diversion from Bighorn River)					
1	Baldridge	19,000	4,490	90	May 1961
2	Sunlight	89,000	2,280	280	May 1961
3	Hunter Mountain	224,000	3,570	570	May 1961
4	Thief Creek	331,000	10,600	600	May 1961
5	2 + 3 + 4	572,000	15,260	260	May 1961
6	All four	585,000	19,510	110	May 1961
(Diversion from Bighorn River = 1.22 million AF)					
1	Baldridge	10,000	4,880	480	May 1961
2	Sunlight	49,000	2,150	150	May 1961
3	Hunter Mountain	134,000	3,310	310	May 1961
4	Thief Creek	204,000	10,300	300	May 1961
5	2 + 3 + 4	350,000	16,480	1,480	April 1941
6	All four	356,000	20,020	620	April 1941

1/ Minimum content observed less minimum allowable content.
2/ Date when minimum content was reached during study period.

Annual summaries for each of these studies are included in this memorandum. A column explanation is included just prior to the summaries.

Below is an index of the summary tables for each study:

Study	Diversion from Bighorn River	
	0 AF	1.22 Million AF
1	14-21	92-105
2	22-35	106-119
3	36-49	120-133
4	50-63	134-147
5	64-77	148-161
6	78-91	162-175

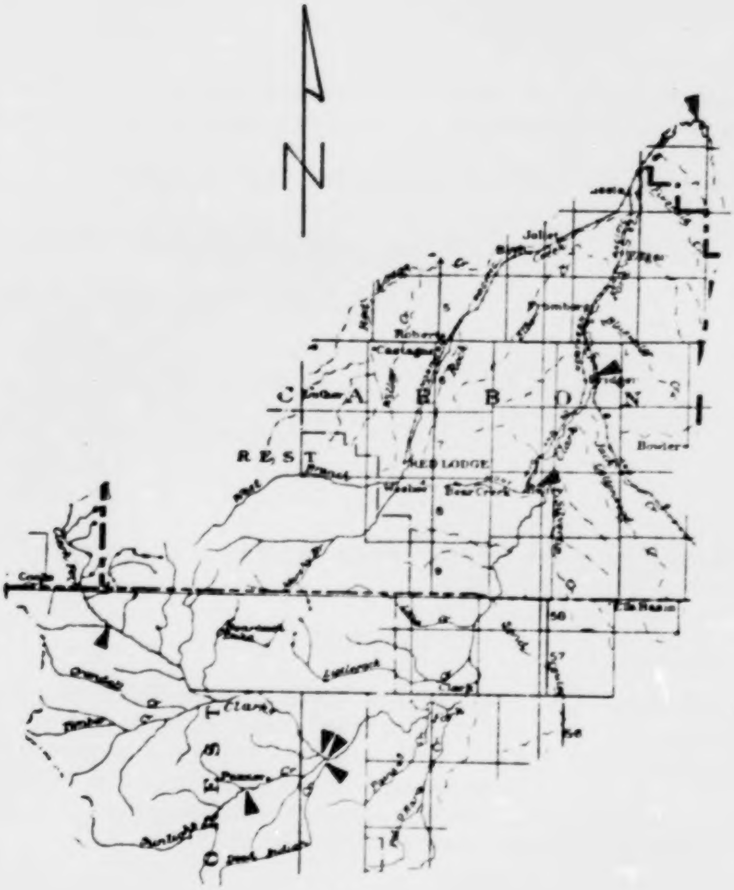
Complete computer printouts of the above studies are contained in the NGPRP Water Work Group files.

CONCLUSIONS

Without any diversion from the Bighorn River, up to 585,000 acre-feet could be developed annually for industrial uses and still meet BSFW instream water needs criteria. This assumes all four reservoirs would be used. Assuming 1.22 million acre-feet diversion from the Bighorn River, a four reservoir system could develop 356,000 acre-feet. For individual reservoirs see the tabulation under RESULTS.

David M. Hairston

I concur: John W. Keys
Regional Hydrologist


N
C A R B O N
R E S T
RED LODGE
Bear Creek
Joliet
Roberts
Fromberg
Bowler
Elk Basin
50
57

CLARKS FORK YELLOWSTONE RIVER BASIN

▲ Point of instream water need (BSFW)

Figure 1

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Table 1- Instream Water Needs Criteria
(CFS)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Clarks Fork River from Pilot Creek to Crandell Creek	42	35	40	115	350	350	350	241	135	102	69	60
to Sunlight Creek	60	60	60	160	400	400	400	350	210	120	73	75
to Dead Indian Creek	80	80	80	188	470	525	525	433	270	168	104	100
to Pat O'Hara Creek	90	90	90	200	500	600	600	450	300	200	120	110
to Belfry	225	225	225	250	1,000	1,000	1,000	385	290	260	225	225
to Bridger	185	180	180	250	1,000	1,000	1,000	385	180	180	225	225
to Mouth	350	350	350	350	1,000	1,000	1,000	350	350	350	350	350
Sunlight Creek from Trail Creek to Mouth	20	20	20	28	70	125	125	83	60	48	31	25
Dead Indian Creek at Mouth	8	8	8	12	31	55	55	36	26	21	14	11
Yellowstone River at Miles City	3,500	3,500	4,200	4,400	10,000	10,000	10,000	5,000	5,000	5,000	4,700	4,400
Yellowstone River at Mouth	3,400	3,500	4,400	4,600	12,000	12,000	12,000	4,000	4,000	4,000	4,000	4,000

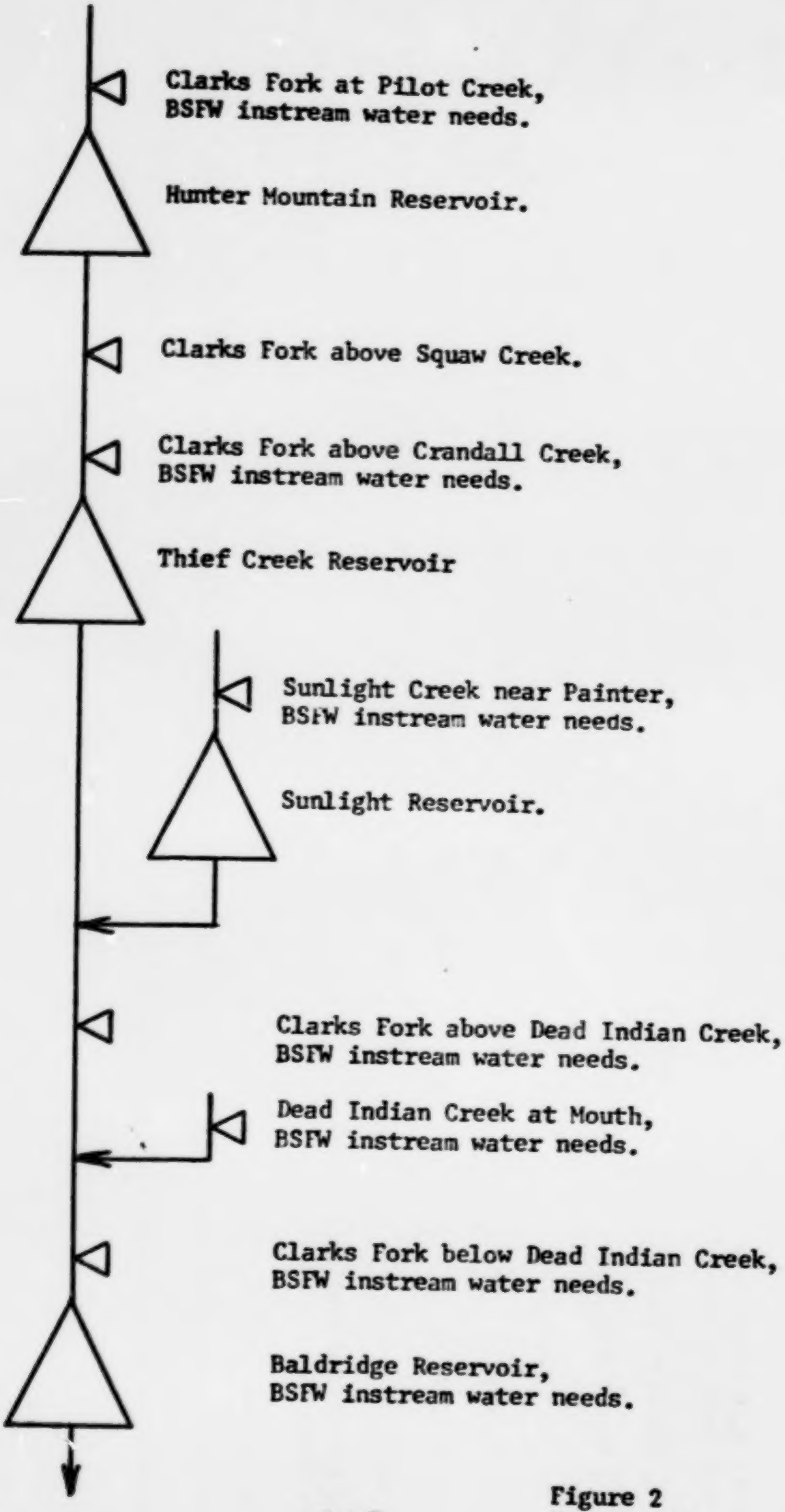
Clarks Fork at Pilot Creek,
BSFW instream water needs.
Hunter Mountain Reservoir.
Clarks Fork above Squaw Creek.
Clarks Fork above Crandall Creek,
BSFW instream water needs.
Thief Creek Reservoir
Sunlight Creek near Painter,
BSFW instream water needs.
Sunlight Reservoir.
Clarks Fork above Dead Indian Creek,
BSFW instream water needs.
Dead Indian Creek at Mouth,
BSFW instream water needs.
Clarks Fork below Dead Indian Creek,
BSFW instream water needs.
Baldridge Reservoir,
BSFW instream water needs.

Figure 2
Page 1 of 2

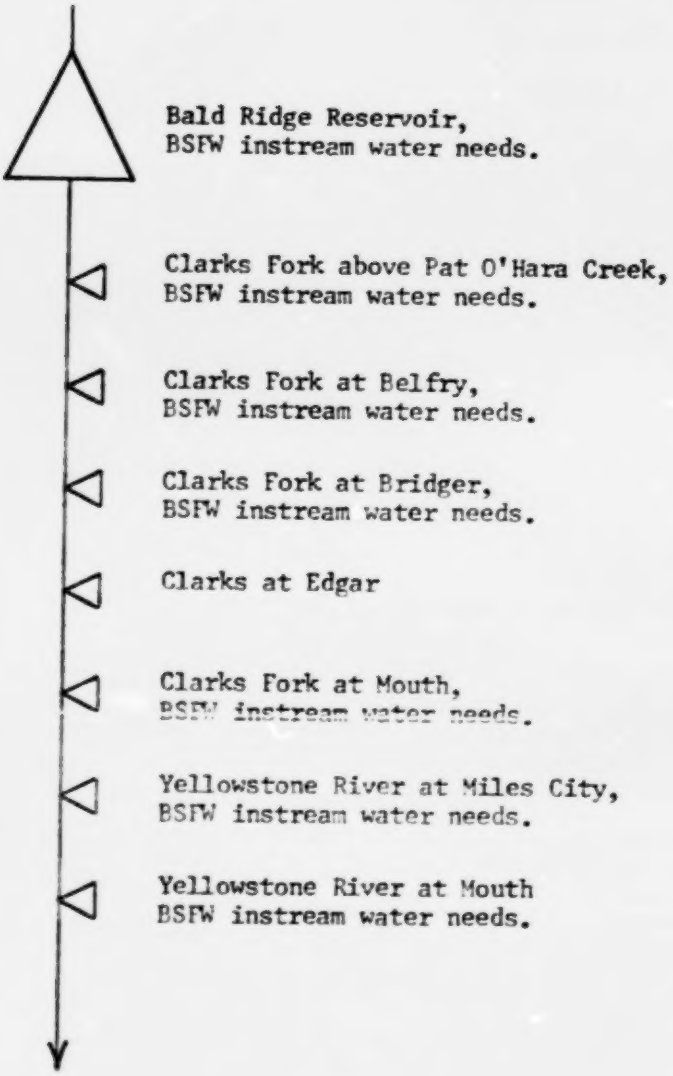
Bald Ridge Reservoir,
BSFW instream water needs.
Clarks Fork above Pat O'Hara Creek,
BSFW instream water needs.
Clarks Fork at Belfry,
BSFW instream water needs.
Clarks Fork at Bridger,
BSFW instream water needs.
Clarks at Edgar
Clarks Fork at Mouth,
BSFW instream water needs.
Yellowstone River at Miles City,
BSFW instream water needs.
Yellowstone River at Mouth
BSFW instream water needs.

Figure 2
Page 2 of 2

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: JUN 13 1974

FROM : David M. Haisten

SUBJECT: Water Supply Analysis, Bighorn River Basin, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water in the Bighorn River Basin.

Headwaters of the Bighorn River rise in the Rocky Mountains of Western Wyoming just southeast of Yellowstone National Park. This portion of the river system is known as the Wind River. The Wind River flows in a southeasterly direction past the City of Riverton, thence northeast where it flows into Boysen Reservoir, draining an area of about 7,700 square miles. The Wind River then flows north through the Wind River Canyon. At the mouth of the Wind River Canyon (northern boundary of the Wind River Indian Reservation), the Wind River changes names to the Bighorn River. This location is called Wedding of the Waters and is about 5 miles south of Thermopolis.

The Bighorn River flows in a northerly direction through north-central Wyoming and south-central Montana to its confluence with the Yellowstone River about 65 miles northeast of Billings. At river mile 81.0, Yellowtail Dam controls the Bighorn River forming Bighorn Lake. Bighorn Lake extends some 40 miles south of the Wyoming-Montana state boundary.

Drainage area at Yellowtail Dam is 19,626 square miles. The Bighorn River drains an area of 22,885 square miles. Many streams flow out of the Rocky (westside) and Bighorn (eastside) Mountain Ranges into the Bighorn River. The major tributaries are the Greybull and Shoshone Rivers in Wyoming and the Little Bighorn River in Montana. A map of the Bighorn Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife instream water needs criteria. The program also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

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All water studies were conducted with runoff figures which reflect the 1970 level of water resources development in the basin.

The various data used in the program are shown below with a short discussion as to source, estimates and assumptions.

1. Instream water needs: Memorandums from the Area Manager, Bureau of Sport Fisheries and Wildlife, Billings, Montana, to Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings, Montana.

    A. December 27, 1973, Subject: Northern Great Plains Resource Program - Estimates of Instream Water Needs for the Clarks Fork, Little Bighorn, Bighorn (below Yellowtail Reservoir) and Yellowstone Rivers.

    B. January 15, 1974, Subject: Northern Great Plains Water Resources Program - Estimates of Instream Needs for the Bighorn River from Boysen Reservoir to Yellowtail Reservoir.

    C. January 15, 1974, Subject: Northern Great Plains Resource Program - Additional instream regimen for the Bighorn River downstream of Yellowtail Reservoir.

    Copies of these memorandums are not attached, but Table 1 summarizes the needs for the Bighorn River and the Yellowstone River below the Bighorn River. The point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2. All runoff reflects the 1970 level of development. Those stations used in the water supply studies are as follows:

    A. Bighorn (Wind) River at Boysen Dam: Inflow at the 1970 level of development through 1963 was obtained from MRB 1/ supporting material. Inflow through 1970 was extended in the same manner as in the MRB framework study.

    B. Bighorn River above Kirby Ditch: Runoff was estimated as the incremental drainage area ratio ((8030-7701)/(11,048-7701) = .098) times the difference in runoff between Bighorn River at Manderson (item 2.F.) and Boysen Reservoir, plus Boysen Reservoir.

1/ Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

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C. Bighorn River above Upper Hanover Canal: Runoff at this point was estimated in the same manner as for Bighorn River above Kirby Ditch. The ratio determined was 0.379 ((8970-7701)/(11,048-7701)).

D. Bighorn River above Bighorn Canal: Runoff was estimated in the same manner as for Bighorn River above Kirby Ditch. The ratio determined was 0.639 ((9840-7701)/(11,048-7701)).

E. Bighorn River above Lower Hanover Canal: Runoff was estimated in the same manner as for Bighorn River above Kirby Ditch. The ratio determined was 0.771 ((10,280-7701)/(11,048-7701)).

F. Bighorn River at Manderson: Runoff at this point was estimated as the drainage area ratio ((11,048-7701)/(15,765-7701-1115) = 0.482) times the difference in MRB 1/ runoff of Bighorn River at Kane, Greybull River near Basin and Boysen Reservoir releases, plus Boysen Reservoir releases. This data was then revised for reservoir operation studies by taking out the effects of Boysen Reservoir. These effects were calculated from the MRB 1/ supporting material.

G. Bighorn River above Greybull River: Runoff was estimated as the drainage area ratio (11,240/11,048 = 1.017) times Bighorn River at Manderson.

H. Bighorn River above Shell Creek: Runoff was estimated as the drainage area ratio (14,890/15,765 = 0.945) times Bighorn River at Kane (item 2.i.).

I. Bighorn River at Kane: 1970 level correction values through 1963 were obtained from MRB 1/ supporting material, extended through 1970, and applied to recorded runoff at this stream gage. This data was then revised in the same manner as for Manderson to remove the effects of Boysen Reservoir.

J. Bighorn River near St. Xavier: Historic inflow to Yellowtail Reservoir was estimated from recorded runoff at the St. Xavier stream gage and 1970 level corrections from MRB 1/ supporting material. An operation study (found in NGPRP supporting material) was conducted to determine the 1970 level inflow and Yellowtail Reservoir releases. The 1970 level inflow was then corrected to remove Boysen Reservoir effects in the same manner as at Manderson.

K. Bighorn River above Two-Leggins Canal: Runoff was estimated as the incremental drainage area ratio ((20,530-19,667)/(22,885-19,667) = 0.268) times the difference in runoff between the mouth of the Bighorn River (item 2.O.) and St. Xavier, plus St. Xavier.

L. Bighorn River above Little Bighorn River (at Hardin): Runoff was estimated in the same manner as for Bighorn River above Two-Leggins Canal. The ratio determined was 0.327 ((20,720-19,667)/(22,885-19,667)).

M. Bighorn River above Lower Bighorn Diversion: Runoff was estimated in the same manner as for Bighorn River above Two-Leggins Canal. The ratio determined was 0.772 ((22,150-19,667)/(22,885-19,667)).

N. Bighorn River at Custer Damsite: Runoff was assumed to be the same as at the mouth (item 2.O.).

O. Bighorn River at Bighorn (Mouth): Runoff for the drainage area below Yellowtail Dam for the common period of record June 1945 through September 1970 was obtained from the two Bighorn River stream gages at Bighorn and near St. Xavier. This incremental runoff was then added to the 1970 level runoff past the St. Xavier gage. For the above common period of record, a monthly ratio of runoff from St. Xavier to the mouth was determined. These monthly ratios were then applied to the 1970 level runoff at the St. Xavier stream gage for the period prior to June 1945 to estimate the 1970 level runoff at the Mouth of the Bighorn River. This runoff was then further adjusted to remove the effects of Boysen and Yellowtail (Bighorn) reservoirs.

P. Yellowstone River at Miles City: Runoff at this point was taken from a previous memorandum report 2/ and then adjusted to remove the effects of Boysen and Yellowtail reservoirs.

Q. Yellowstone River at Mouth: Runoff at this point was taken from a previous memorandum report 2/ and then adjusted to remove the effects of Boysen and Yellowtail reservoirs.

2/ Water Supply Analysis, Yellowstone River Basin, Allenspur Reservoir and Offstream Storage Only, Northern Great Plains Resource Program, Memorandum report to Regional Hydrologist dated March 19, 1974.

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3. Area-capacity curves for Boysen and Yellowtail reservoirs and Custer reservoir site are shown on Figures 3, 4, and 5.

4. Reservoir evaporation rates were obtained from the 1950 Yellowtail Unit Definite Plan Report (2.10 feet for Yellowtail and Custer Reservoirs) and water supply studies for Boysen Reservoir (2.90 feet) conducted in 1969.

5. Water years 1935 through 1970 were used as the study period since this period represents the longest period of runoff records available for all stations used on the Bighorn River. All runoff used represents 1970 level of development.

6. Reservoir capacities for Boysen and Yellowtail reservoirs were obtained from area-capacity curves and Reservoir Capacity Allocation sheets on file in our office. Capacities for Custer reservoir site were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Reservoir contents used are shown below:

Reservoir	Maximum (Acre-feet)	Active (Acre-feet)	Minimum (Acre-feet)
Boysen	802,000	550,000	252,000
Yellowtail (Bighorn)	1,116,000	614,000	502,000
Custer	501,000	401,000	100,000

7. Flood control was not considered in this study except that exclusive flood control space in the existing Boysen and Yellowtail reservoirs was not used as part of the active contents.

8. Because of the Wind River Indian Reservation, provision for the irrigation of 50,000 acres of Indian lands was included as a project function. Also, irrigation of 9,000 acres on Cottonwood Bench was included since this development is going on at the present time. Diversion requirement of 5.0 acre-feet per acre and return flow of 3.0 acre-feet per acre for these 59,000 acres were taken from reports on the Riverton Project. The gross diversion requirement for irrigation water service to these lands would be about 295,000 acre-feet per year and the net diversion requirement would be 118,000 acre-feet annually. Water for all lands was assumed to be diverted from Boysen Reservoir with return flow accruing to the Wind River above Boysen Reservoir.

9. Water in Bighorn Lake has been reserved for future irrigation of 36,000 acres on the Crow Indian Reservation and 8,000 acres on Hardin Bench. At an annual rate of 1.70 acre-feet per acre [3], the irrigation of 44,000 acres would deplete flows of the Bighorn River by approximately 75,000 acre-feet annually. To allow for the irrigation of these lands below Yellowtail Dam, water available for industrial diversion was reduced by 75,000 acre-feet per year.

10. Study criteria:

    A. Water in excess of instream needs could be stored or diverted.

    B. When runoff drops below instream needs, water could not be stored or diverted.

    C. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but releases for instream needs were not considered a project function.

    D. Industrial diversions were provided at a constant rate throughout the year.

    E. No shortages were allowed for industrial diversions.

    F. Because of limited time, new irrigation (except for item 8) was not considered in separate water supply studies. Should information be desired for new irrigation, water supply for its development could be taken from the total available water from the basin. Industrial diversion potential would then be reduced by that amount.

11. Reservoir operation studies did not include all stream points. Only critical BSFW stream points, reservoir sites, and needed runoff stream points were used in the analysis.

RESULTS AND STUDY DISCUSSIONS

Several water supply studies were conducted to determine the maximum possible diversion for industrial uses. Because of the existence of Boysen and Yellowtail reservoirs, these reservoirs were generally included in the individual studies.

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[3] Table 36, Definite Plan Report, Hardin Unit, Lower Bighorn Division, Missouri River Basin Project, Appendix III - Water Supply, January 1960.

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Two operation studies were conducted with no reservoirs or diversions. Summaries of flow shortages (instream needs less runoff) for each BSFW stream point are included in this memorandum for comparison with other studies. One study was run using 1970 level runoff with Boysen and Yellowtail effects included (Tables 8 through 21). The other study was run using 1970 level runoff with the reservoir effects removed (Tables 22 through 35). This last study indicates the flow shortages as if Boysen and Yellowtail Dams were not in place.

Results of the various reservoir operation studies are shown below with a short discussion of each study following the tabulation.

	Reservoir	Diversion (Acre-feet)	Minimum Content Obtained (Acre-feet)	Smallest Surplus 1/ (Acre-feet)	Date 2/
1.	Boysen 3/	111,000	252,300	300	March 1941
	Yellowtail	0	-	-	
2.	Boysen 3/	111,000	252,300	300	March 1941
	Yellowtail 3/	133,000	503,050	750	Jan 1962
3.	Boysen 3/	111,000	252,300	300	March 1941
	Yellowtail 4/	167,000	504,180	2,180	August 1961
4.	Boysen 3/	111,000	252,300	300	March 1941
	Yellowtail 5/	298,000	502,690	390	August 1961
5.	Boysen 6/	0	252,300	300	March 1941
	Yellowtail 4/ 6/	833,300	502,300	0	August 1961
6.	Boysen 3/ 6/	85,000	252,300	300	March 1941
	Yellowtail 4/ 6/	833,300	502,300	0	August 1961
7.	Boysen 6/	0	252,300	300	March 1941
	Yellowtail 4/ 6/	833,300	502,300	0	August 1961
8.	Boysen 6/	111,000	252,300	300	March 1941
	Yellowtail 6/	0	502,600	600	Jan 1962
	Custer 3/ 6/	319,000	97,380 7/	0	Jan 1963

1/ Minimum content obtained less minimum allowable content.
2/ Date when minimum content was reached during study period.
3/ Diversion from reservoir.
4/ Diversion at Hardin (above Little Bighorn River).
5/ Diversion at Miles City.
6/ See study discussion.
7/ Minimum contents observed are less than the minimum allowable contents (100,000 acre-feet) because of evaporation losses. No shortage to diversion or increase of shortage to instream needs criteria were allowed.

All reservoir operation studies used 1970 level runoff with Boysen and Yellowtail reservoir effects removed. Also, not all BSFW stream points were included in the following studies; only the major runoff stream points and the most critical BSFW instream need stream points were used.

Study 1 used Boysen Reservoir only in order to determine the maximum possible industrial diversion from Boysen Reservoir for use in further studies.

Studies 2, 3, and 4 determined the maximum possible industrial diversion using Yellowtail storage. Each of these three studies used a different diversion point.

Study 5 was conducted to fit a scenario diversion of 1,151 cubic feet per second (833,300 acre-feet annually) at Hardin. A criteria of zero industrial diversion from Boysen Reservoir was used. In order to fully utilize Boysen Reservoir, meet the above criteria, and fit the computer program, diversion of 111,000 acre-feet was made with the same quantity returned to the Bighorn River as return flow below Boysen Dam. Also, in order to follow the criteria of zero shortage for industrial diversion, it was necessary to reduce the instream needs criteria to 55 percent of the BSFW operational alternative flows below Yellowtail Dam. Flow requirements were not placed on the Yellowstone River in this study for convenience. For operation studies concerning the Yellowstone River, see memorandum report dated March 19, 1974, Subject: Water Supply Analysis, Yellowstone River Basin, Allenspur Reservoir and Offstream Storage Only, Northern Great Plains Resource Program. Effects of the scenario diversion on the Yellowstone River as compared to BSFW's instream water needs are shown on Tables 2 and 3.

Study 6 was conducted to fit the same scenario as in study 5, plus a diversion of 85,000 acre-feet from Boysen Reservoir which is the amount of water under option contracts. In order to fully utilize Boysen Reservoir and to fit the computer program, 111,000 acre-feet was diverted from Boysen Reservoir with a return flow of 26,000 acre-feet downstream, leaving a net diversion of 85,000 acre-feet. In order to meet the criteria of zero shortage to industrial diversion, it was necessary to reduce the instream needs to 48 percent of the BSFW operational alternative flows below Yellowtail Dam. As in study 5, flow requirements were not placed on the Yellowstone River. Tables 4 and 5 show flow shortages for the Yellowstone River at Miles City and at the mouth.

Study 7 is the same as study 5 except that whenever possible the full instream needs criteria was used. The following tabulation shows the time spans in which each flow requirement was used:

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Water Years	Full Instream Needs	55% Operational Alternative
1935	X	
1936 - 1940		X
1941 - 1952	X	
1953 - 1962		X
1963 - 1970	X	

Tables 6 and 7 show flow shortages for the Yellowstone River at Miles City and at the mouth using BSFW instream water needs criteria.

Study 8 utilizes Boysen and Yellowtail (as in study 2) plus the addition of a possible storage site (Custer) near the mouth of the Bighorn River. As before, in order to fully utilize the existing reservoirs and to fit the computer program, a diversion of 111,000 acre-feet was made from Boysen Reservoir with a return flow of like amount below the dam. Full instream needs were used as the flow requirement at all stream points in the system.

Annual summaries for each of these studies are included in this memorandum. A column explanation for the summaries is included just prior to the summaries.

The following tabulation is an index to the summary tables for each water supply study discussed above:

Study	Tables
1	36 - 44
2	45 - 53
3	54 - 62
4	63 - 71
5	72 - 80
6	81 - 89
7	90 - 98
8	99 - 107

Complete computer printouts of the above studies are contained in the NGPRP Water Work Group files.

CONCLUSIONS

Using the existing Boysen and Yellowtail (Bighorn Lake) reservoirs, 111,000 acre-feet from Boysen Reservoir and up to 298,000 acre-feet from

Yellowtail Reservoir can be developed for industrial uses. With the addition of Custer Reservoir, 111,000 acre-feet from Boysen Reservoir and 319,000 acre-feet from Custer Reservoir could be developed. In order to meet the scenario diversion of 1,151 cubic feet per second (833,300 acre-feet per year) at Hardin, a reduction of instream water needs below Hardin during low flow years would be necessary.

David M. Hairston

I concur: John W. Keys, III
Regional Hydrologist

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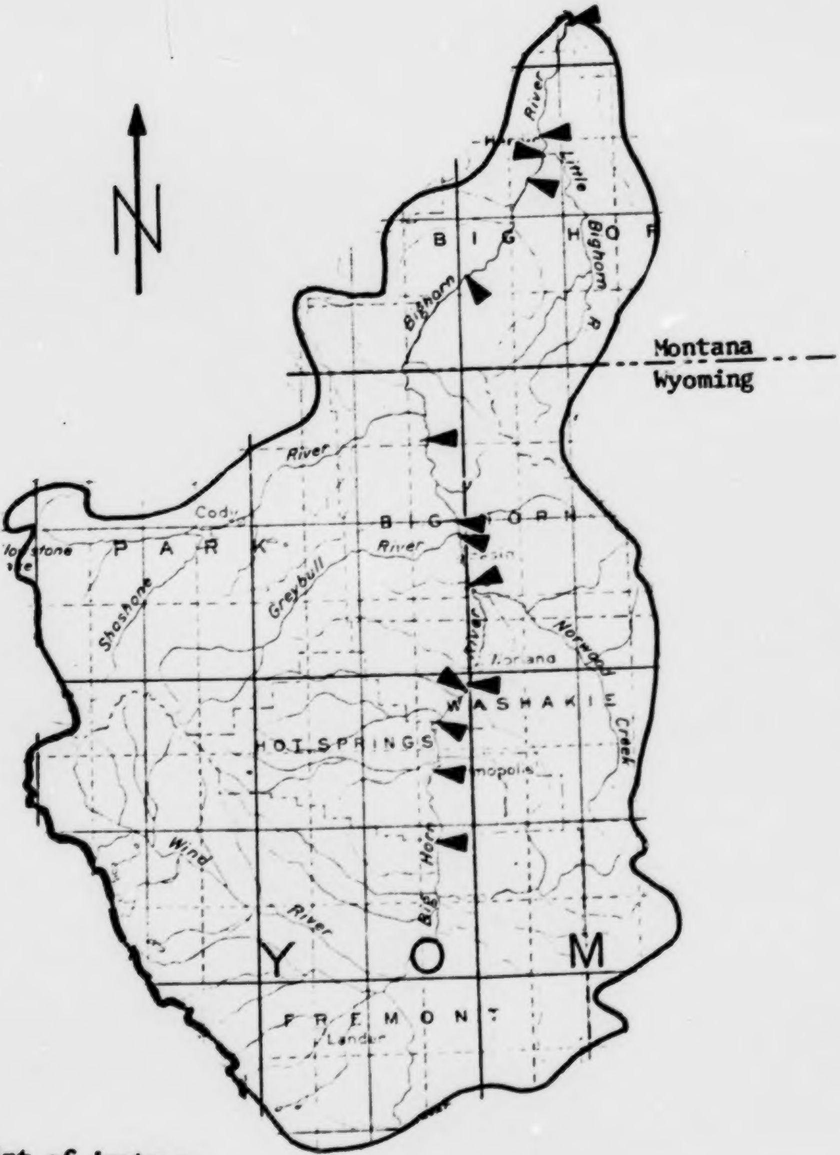
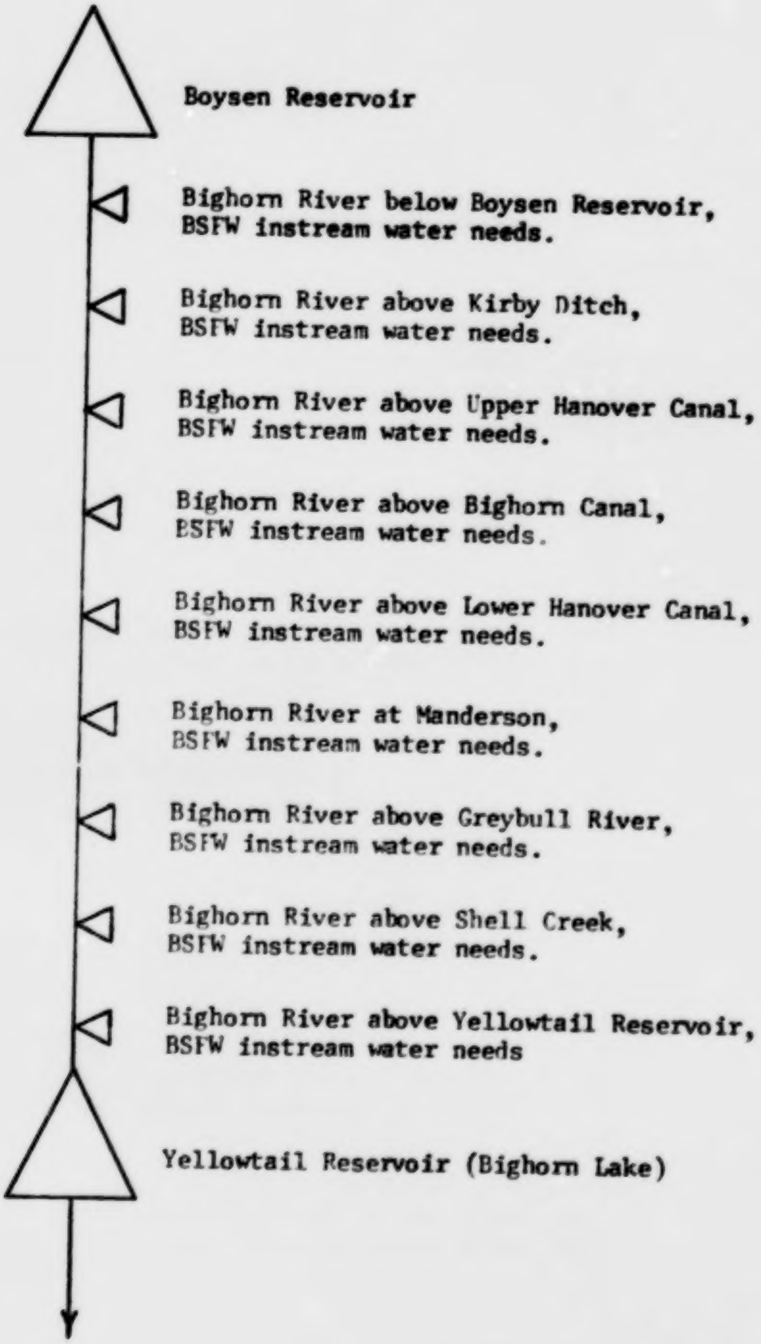

N
Montana
Wyoming
River
Horn
Little
BIG HOR
Bighorn R
Bighorn
River
Cody
lowstone
ke
B I G H O R N
P A R K
River
Basin
Shoshone
Greybull
River
Norwood Creek
Worland
W A S H A K I E
HOT SPRINGS
mopolis
Wind
River
Big Horn
Y O M
F R E M O N T
Lander

▲ Point of instream water need (BSFW)

BIGHORN RIVER BASIN

Figure 1



Boysen Reservoir

Bighorn River below Boysen Reservoir,
BSFW instream water needs.

Bighorn River above Kirby Ditch,
BSFW instream water needs.

Bighorn River above Upper Hanover Canal,
BSFW instream water needs.

Bighorn River above Bighorn Canal,
BSFW instream water needs.

Bighorn River above Lower Hanover Canal,
BSFW instream water needs.

Bighorn River at Manderson,
BSFW instream water needs.

Bighorn River above Greybull River,
BSFW instream water needs.

Bighorn River above Shell Creek,
BSFW instream water needs.

Bighorn River above Yellowtail Reservoir,
BSFW instream water needs

Yellowtail Reservoir (Bighorn Lake)

Figure 2

Page 1 of 2

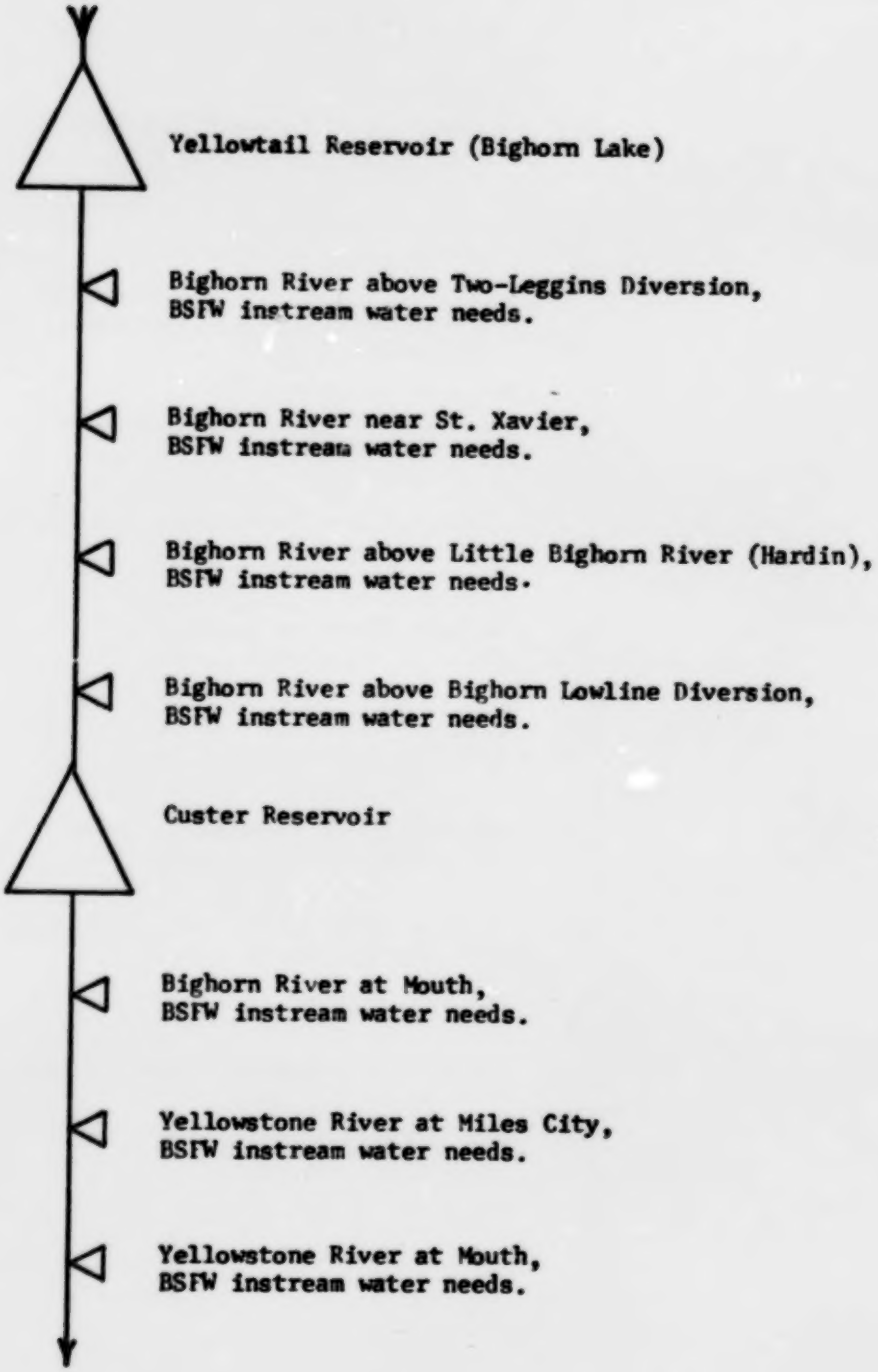

Yellowtail Reservoir (Bighorn Lake)
Bighorn River above Two-Leggins Diversion, BSFW instream water needs.
Bighorn River near St. Xavier, BSFW instream water needs.
Bighorn River above Little Bighorn River (Hardin), BSFW instream water needs.
Bighorn River above Bighorn Lowline Diversion, BSFW instream water needs.
Custer Reservoir
Bighorn River at Mouth, BSFW instream water needs.
Yellowstone River at Miles City, BSFW instream water needs.
Yellowstone River at Mouth, BSFW instream water needs.

Figure 2

Page 2 of 2

Table 1 - Instream Water Needs
(CFS)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bighorn River:												
Boysen Reservoir to Kirby Diversion	750	750	750	750	1,000	1,050	1,050	1,050	1,050	775	750	750
To Upper Hanover Canal	750	750	750	750	975	1,025	1,025	1,025	1,025	750	750	750
To Bighorn Canal	650	650	650	650	800	800	800	800	800	650	650	650
To Lower Hanover Canal	650	650	650	300	400	400	330	330	330	330	650	650
To Manderson	650	650	650	460	610	610	585	575	525	475	650	650
To Greybull River	650	650	650	520	675	675	665	650	595	530	650	650
To Shell Creek	700	700	700	700	900	1,450	700	700	700	700	700	700
To Yellowtail Reservoir (Bighorn Lake)	1,000	1,000	1,000	1,000	1,200	1,450	700	700	800	1,000	1,000	1,000
Yellowtail Afterbay To Two Leggins Diversion	2,000	2,000	2,000	2,000	2,000	3,300	2,000	2,000	2,000	2,000	2,000	2,000
To Little Bighorn River	2,000	2,000	2,000	2,000	2,000	3,300	1,750	1,750	1,800	1,800	2,000	2,000
To Bighorn Lowline Diversion	2,100	2,100	2,100	2,100	2,300	3,500	1,900	1,900	1,900	1,900	2,100	2,100
To Mouth	2,100	2,100	2,100	2,100	2,100	3,400	1,800	1,800	1,800	1,850	2,100	2,100
Little Bighorn River:												
Montana-Wyoming State line to Pass Creek	65	61	61	65	150	110	150	117	96	84	72	66
To Lodgegrass Creek	100	110	113	125	200	200	130	106	107	128	122	108
To Crow Agency	100	100	100	125	270	270	125	75	70	100	100	100
To Mouth	100	100	125	200	350	350	200	100	100	100	100	100
Yellowstone River:												
Bighorn River to Miles City	3,500	3,500	4,200	4,400	10,000	10,000	10,000	5,000	5,000	5,000	4,700	4,400
To Lower Yellowstone Canal	3,600	3,600	4,400	4,600	10,500	10,500	10,500	5,100	5,100	5,100	4,800	4,500
To Sidney	3,500	3,500	4,400	4,600	10,500	10,500	10,500	4,000	4,000	4,000	4,000	4,000
To Mouth	3,400	3,500	4,400	4,600	12,000	12,000	12,000	4,000	4,000	4,000	4,000	4,000
Operational Alternatives:												
Bighorn River:												
Two Leggins Diversion to Little Bighorn River	1,500	1,500	1,500	1,500	1,500	3,000	1,500	1,500	1,500	1,500	1,500	1,500
To Bighorn Lowline Diversion	1,600	1,600	1,625	1,700	1,850	3,350	1,700	1,600	1,600	1,600	1,600	1,600
To Mouth	1,600	1,600	1,625	1,700	1,650	3,250	1,600	1,500	1,500	1,550	1,600	1,600
Yellowstone River:												
Miles City to Lower Yellowstone Canal	3,100	3,100	3,100	3,100	10,500	10,500	10,500	4,200	4,100	3,300	3,100	3,100
To Sidney	3,000	3,000	3,000	3,000	10,500	10,500	10,500	3,000	3,000	3,000	3,000	3,000
To Mouth	3,300	3,300	3,300	3,300	11,500	11,500	11,500	3,500	3,500	3,500	3,500	3,500

UNITED STATES GOVERNMENT

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Memorandum

TO : Regional Hydrologist

DATE: January 14, 1974

FROM : David M. Haisten, Hydraulic Engineer

SUBJECT: Water Supply Analysis. Tongue River Basin, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water in the Tongue River Basin and the quantity available for diversion for industrial purposes.

The Tongue River rises in the Big Horn Mountains of northern Wyoming and flows north and eastward through Wyoming into Montana, finally joining the Yellowstone River at Miles City in eastern Montana. The Tongue River Basin is approximately 150 miles long and 40 miles wide with a drainage area of nearly 5,400 square miles. The major water-producing area of the Tongue River drainage lies in the Big Horn Mountains on the tributaries North Tongue River, South Tongue River, Little Tongue River, Wolf Creek, Goose Creek, and Little Goose Creek. A number of ephemeral streams join the Tongue River from the north. Prairie Dog Creek rises in the plains south and east of Sheridan and joins the main Tongue River just before it crosses the border into Montana. In Montana, many small ephemeral tributaries flow into the northward-flowing Tongue River from the west. On the east, however, drainage is dominated by three major tributaries: Hanging Woman Creek, which joins the main river at Birney; Otter Creek, which joins at Ashland; and Pumpkin Creek, which flows into the Tongue River about 22 river miles above the confluence of the Tongue and Yellowstone Rivers at Miles City. A map showing the Tongue River Drainage Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The program also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

All water studies were conducted with runoff figures which reflect the 1970 level of water resources development in the basin.

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

The various data used in the program are shown below with a short discussion as to source, estimates and assumptions.

1. Instream water needs: Memorandum dated October 18, 1973, to Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings, Montana, From: Area Manager, Bureau of Sport Fisheries and Wildlife (ES/1100:660), Subject: Northern Great Plains Resource Program - Estimates of Instream Water Needs for Tongue River. A copy of this memorandum is not attached, but Table 1 summarizes the instream water needs. The point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2. All runoff data reflect the 1970 level of development.

   A. Tongue River at Rockwood Damsite: Runoff was estimated as the drainage area ratio (191/204=0.936) times the sum of recorded runoff of the Tongue River near Dayton and recorded Highline Ditch Diversions.

   B. Tongue River above Highline Ditch Diversion: Runoff was estimated as the recorded Tongue River near Dayton plus recorded Highline Ditch Diversions. Runoff for water years 1939 and 1940 was estimated from a correlation of Tongue River near Dayton (including diversions) with Big Goose Creek near Sheridan (Figure 3).

   C. Tongue River near Dayton: Records of runoff are available for October 1918 through September 1929 and October 1940 to date. Recorded runoff since 1940 was assumed to be representative of 1970 level of development. Water years 1939 and 1940 were estimated by subtracting the average Highline Ditch diversion for 1941-1942 from the estimated natural runoff determined for Tongue River above Highline Ditch (Item 2.B. above).

   D. Tongue River above Wolf Creek: Runoff at this point was estimated to be 1.152 times the runoff pass the gaging station Tongue River near Dayton. This factor was determined by a drainage area ratio of the runoff between the Dayton streamgage (recorded) and above Goose Creek (estimated, see next section), the runoff then being applied to the Dayton gage runoff (Figure 4).

E. Tongue River above Goose Creek: Runoff at this location is estimated to be 1.406 times the recorded runoff of Tongue River near Dayton. The runoff above Goose Creek was estimated by taking the difference in runoff for the common period of record, 1942-1946, between Tongue River near Acme and Goose Creek below Sheridan. All of this runoff was assumed to occur above Goose Creek. The factor was then determined by applying the above derived runoff to records of flow at the Dayton gage (Figure 5).

F. Tongue River at Stateline Damsite: From information obtained from the 1973 Pacific Power and Light report on the Tongue River Basin in Wyoming, runoff at this stream point was estimated to be about 93 percent of the inflow to Tongue River Reservoir (Figure 6).

G. Tongue River at Tongue River Dam:[1/] Runoff at this stream point was obtained from the MRB[1/] study for the period October 1928 through September 1963. Records for the streamgage Tongue River at Stateline, near Decker, were adjusted in similar manner to extend the runoff data through September 1970. This runoff was assumed to be the inflow to the New Tongue Reservoir.

H. Tongue River above T&Y Diversion (above Pumpkin Creek): Estimated 1970 level runoff at this point was determined by taking the drainage area ratio of the difference in runoff between the stream points at Miles City and at Tongue River Reservoir plus at Tongue River Reservoir (Figure 7).

I. Tongue River at Miles City: The recorded runoff at this gaging station was adjusted to the 1970 level of development in the MRB[1/] study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB study, to obtain 32 years of runoff data.

3. Area-capacity curves for the various reservoir sites investigated were obtained from various reports and files in the Division of Planning (Figures 8, 9, 10, and 11).

4. Reservoir evaporation rates were assumed to be the same as used for Moorhead Reservoir in the 1950 Definite Plan Report, 2.68 feet.

[1/] Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

5. Water years 1939 through 1970 were used as the study period since these records represent the longest period of runoff records available for all stations on the Tongue River. These records were adjusted to show the 1970 level of development within the basins.

6. Reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. The active storage content in Rockwood Reservoir was determined by using the anticipated sediment inflow of 15,000 acre-feet as the minimum content. Minimum contents for the other reservoirs are the differences between maximum and active contents taken from the table mentioned above. Reservoir capacities used in this study are shown below:

Reservoir	Maximum (Acre-feet)	Active (Acre-feet)	Minimum (Acre-feet)
Rockwood	113,000	98,000	15,000
Stateline	203,600	195,600	8,000
New Tongue	320,000	316,000	4,000
North Prairie Dog	39,900	36,400	3,500

7. Flood control was not considered for this study.

8. Study criteria:

   A. Water in excess of instream needs could be stored or diverted.

   B. When runoff drops below instream needs, water could not be stored or diverted.

   C. Instream water needs, when less than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but these releases were not considered a project function.

   D. Industrial diversions were provided at a constant rate throughout the year.

   E. No shortages were allowed for industrial diversions.

   F. No new irrigation.

RESULTS

Seven water supply studies were conducted to determine the maximum possible diversion for industrial uses. Four of these studies (1, 2, 4, and 6) were single reservoir systems. The other three studies (3, 5, and 7) were two-reservoir systems with each of the three downstream reservoirs operated in conjunction with Rockwood Reservoir site.

Results of the various studies are shown below:

Study	Diversion	Reservoir	Minimum Content Obtained	Smallest Surplus[1]	Date[2]
1	29,000[3]	Rockwood	16,740	1,740	March 1962
2	63,000[3]	New Tongue	4,000	0	Jan. 1962
3	70,000[3]	New Tongue	4,400	400	Jan. 1962
		Rockwood	15,170	170	March 1962
		Both	19,880	880	Jan. 1962
4	46,000[4]	Stateline	8,970	970	Jan. 1962
5	57,000[4]	Stateline	8,450	450	Jan. 1962
		Rockwood	15,350	350	March 1962
		Both	24,340	1,340	Jan. 1962
6	15,000[5]	North Prairie Dog	3,510	10	Jan. 1962
7	38,000[5]	North Prairie Dog	3,950	450	Jan. 1962
		Rockwood	16,580	1,580	March 1962
		Both	20,670	2,170	Jan. 1962

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[1] Minimum content obtained less minimum allowable content.
[2] For 1939-1970 study period.
[3] Diversion at New Tongue Reservoir site.
[4] Diversion at Stateline Reservoir site.
[5] Diversion at North Prairie Dog Reservoir site.

Complete computer printouts of the above studies are in the NGPRP Water Work Group files. Annual summaries of each study are attached as Appendix A.

CONCLUSIONS

Up to 70,000 acre-feet of water can be developed annually from the Tongue River for industrial uses (assuming no shortages and a two-reservoir system) and still meet BSFW's instream water needs criteria. A single reservoir system would yield about 63,000 acre-feet from the river.

David M. Haisten

Attachments

I concur: David M. Haisten
Acting Regional Hydrologist

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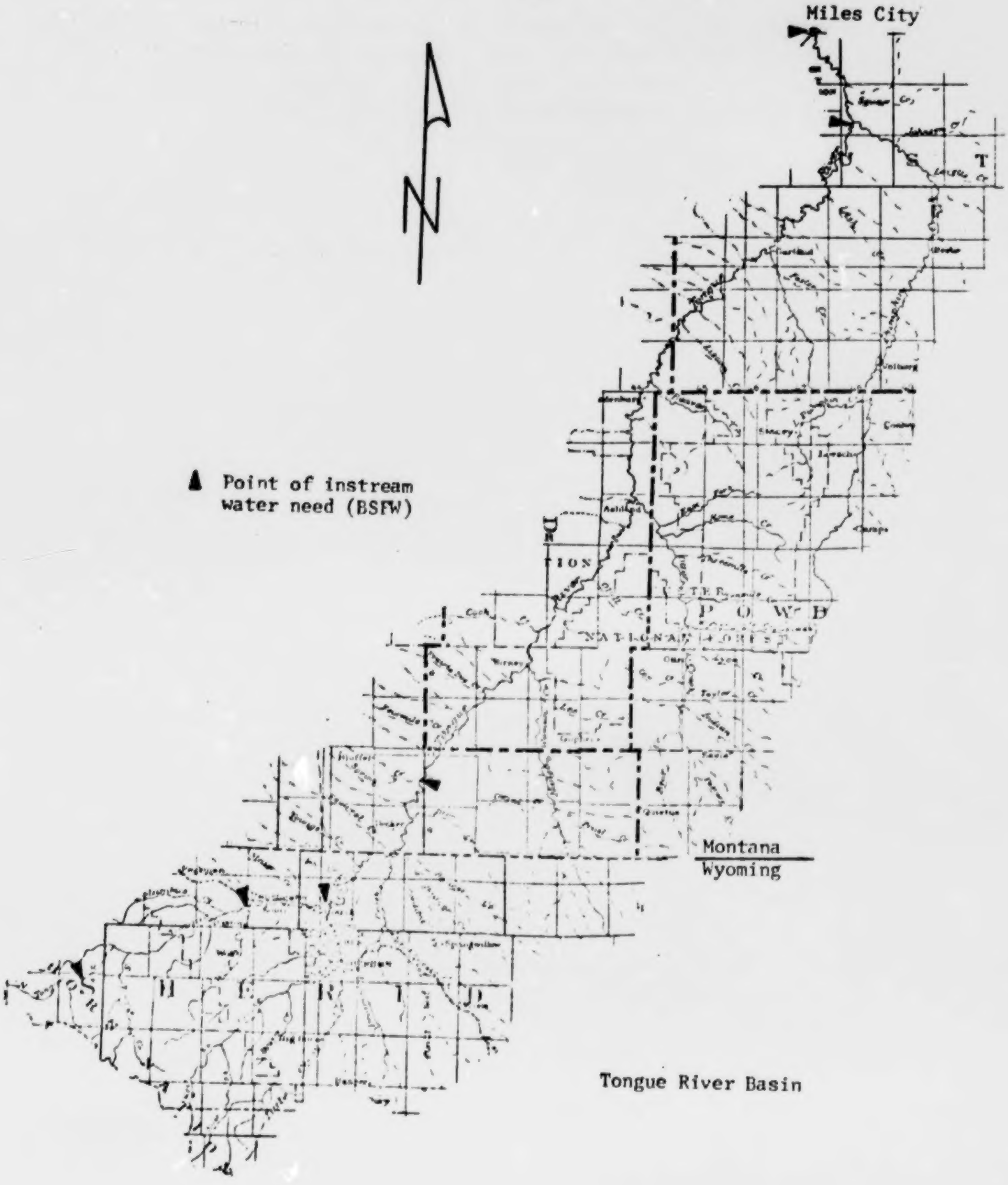
Miles City
▲ Point of instream water need (BSFW)
N
Montana
Wyoming
Tongue River Basin

Figure 1

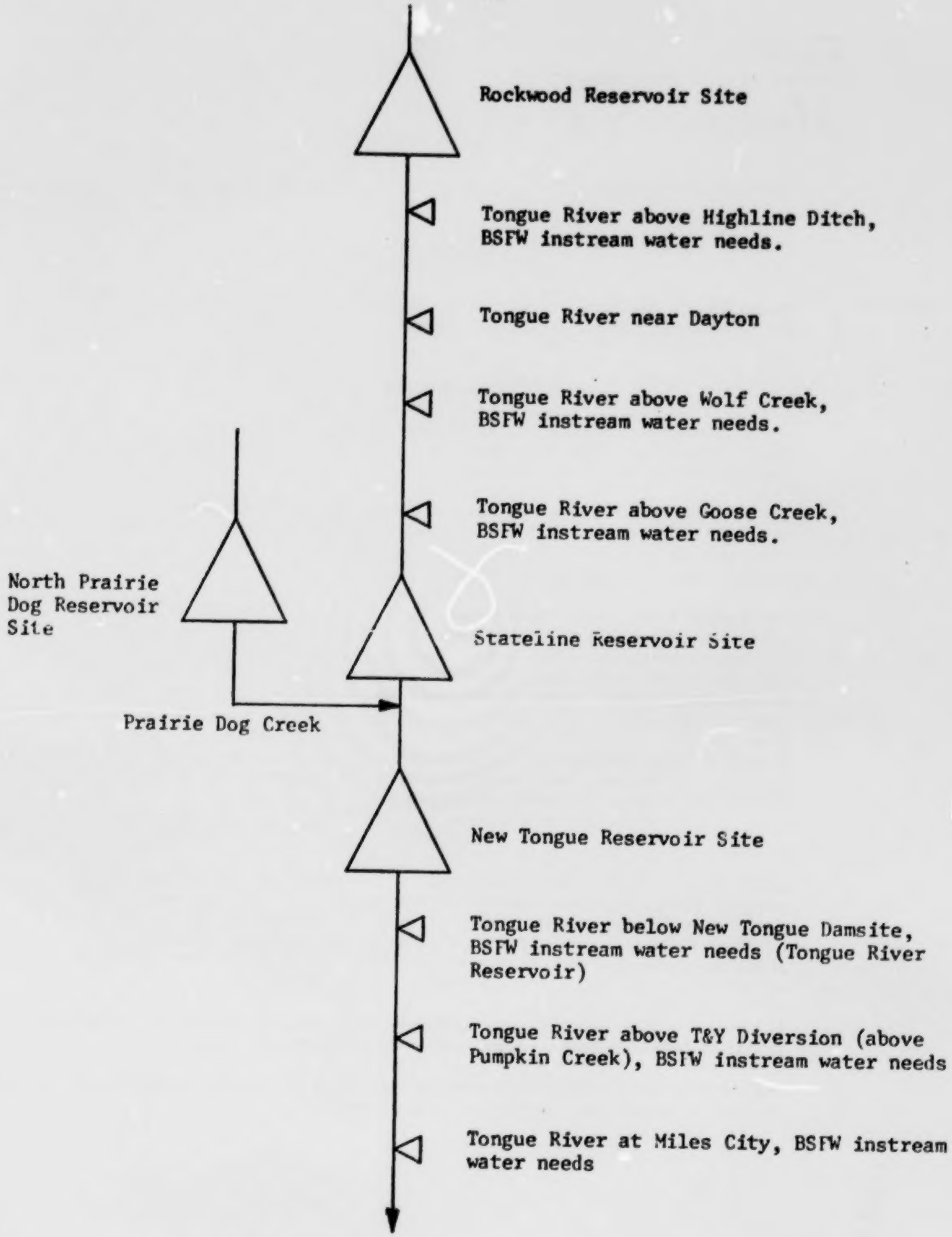
Rockwood Reservoir Site
Tongue River above Highline Ditch, BSFW instream water needs.
Tongue River near Dayton
Tongue River above Wolf Creek, BSFW instream water needs.
Tongue River above Goose Creek, BSFW instream water needs.
North Prairie Dog Reservoir Site
Stateline Reservoir Site
Prairie Dog Creek
New Tongue Reservoir Site
Tongue River below New Tongue Damsite, BSFW instream water needs (Tongue River Reservoir)
Tongue River above T&Y Diversion (above Pumpkin Creek), BSFW instream water needs
Tongue River at Miles City, BSFW instream water needs

Figure 2

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: March 7, 1974

FROM : David M. Haisten, Hydraulic Engineer

SUBJECT: Water Supply Analysis, Powder River Basin
Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water in the Powder River Basin and determine the quantity of water that could be diverted for industrial purposes.

The headwaters of the Powder River rise in the Big Horn Mountains of northcentral Wyoming and flow in a northeasterly direction through Wyoming into Montana. The Powder River flows into the Yellowstone River a few miles upstream of the city of Terry in eastern Montana.

The Powder River Basin is approximately 270 miles long and 100 miles wide with a drainage area of about 13,415 square miles. The major water-producing area lies in the Big Horn Mountains above the Middle Fork and North Fork Powder River (tributaries which join to form the main Powder River), South Fork Powder River, Crazy Woman Creek, and Clear Creek, all of which are in Wyoming. A number of ephemeral streams also join the Powder River, including the Little Powder River which drains a large portion of the prairie lands east of the Powder River in Wyoming and Montana, and the Mizpah River in Montana. A map of the Powder River Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operating studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The model also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

All water supply studies were conducted with runoff figures which reflect the 1970 level of water resources development in the basin.

The various data used in the program are shown below with a short discussion as to source, estimates, and assumptions.

5010-108

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

1. Instream water needs: Memorandum dated November 20, 1973; To: Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings, Montana; From: Area Manager, Bureau of Sport Fisheries and Wildlife, Billings, Montana; Subject: Northern Great Plains Resource Program - Estimates of Instream Water Needs for the Powder River Basin. A copy of this memorandum is not attached, but Table 1 summarizes the needs. The point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2. All runoff reflects the 1970 level of development. Those stations used in the Powder River water supply studies are as follows:

   A. Middle Fork Powder River above Beaver Creek: Runoff was estimated as the drainage area ratio (354/450 = 0.787) times the runoff of Middle Fork Powder River above Kaycee (Hole-in-the-Wall Damsite).

   B. Middle Fork Powder River at Hole-in-the-Wall Damsite: Runoff was assumed to be the same as the gaging station Middle Fork Powder River above Kaycee. Records are available from April 1949 through September 1970. Missing records from October 1929 through March 1949 were obtained from the Bureau of Reclamation Powder Division Report, Hydrology Appendix, November 1955 (Table III-3). Recorded runoff was assumed to be representative of 1970 level conditions.

   C. Middle Fork Powder River above Red Fork: Runoff was estimated as the drainage area ratio (482/450 = 1.071) times the runoff of Middle Fork Powder River above Kaycee (Hole-in-the-Wall Damsite).

   D. Middle Fork Powder River above North Fork: Runoff was estimated as the incremental drainage area ratio ((670-450)/(980-450) = 0.415) times the difference in runoff between Powder River above Sussex Canal (item 2.E.) and Middle Fork Powder River at Hole-in-the-Wall Damsite plus Middle Fork Powder River at Hole-in-the-Wall Damsite.

   E. Powder River above Sussex Canal: Runoff was estimated as the recorded runoff of Powder River near Kaycee plus estimated Sussex Canal diversions. October 1929 through September 1953 were obtained from Table III-2, Bureau of Reclamation Powder Division Report, Hydrology Appendix, November 1955. October 1953 through September 1970 were extended in the same manner.

F. Powder River above South Fork: Runoff was assumed to be same as the runoff of Powder River near Kaycee. Records are available from November 1933 through May 1935 (fragmentary), May 1938 through June 1940, and October 1940 through September 1971. By observation, runoff for July through September 1940 was estimated as zero. October 1937 through April 1938 was estimated as the runoff above Sussex Canal, since there would be little or no diversion into the canal during this period.

G. Powder River at Pumpkin Damsite: Runoff was estimated as the drainage area ratio (4960/(6050-945) = 0.815) times the difference in runoff of Powder River at Arvada (item 2.L.) and Crazy Woman Creek at upper station, near Arvada (item 2.J.).

H. Powder River above Crazy Woman Creek: Runoff was estimated as the drainage area ratio (4960/(6050-945) = 0.972) times the difference in runoff of Powder River at Arvada (item 2.L.) and Crazy Woman Creek at upper station, near Arvada (item 2.J.).

I. Crazy Woman Creek at Lower Crazy Woman Damsite: Runoff was estimated as the drainage area ratio (931/945 = 0.985) times Crazy Woman Creek at upper station, near Arvada (item 2.J.).

J. Crazy Woman Creek at upper station, near Arvada: Recorded runoff was estimated to approximate 1970 level runoff. Records are available from April 1963 through September 1970. Runoff from October 1938 through March 1963 was estimated by a correlation (Figure 3) with the 1970 level Powder River at Arvada (item 2.L.).

K. Crazy Woman Creek at Mouth: Runoff was estimated as the drainage area ratio (960/945 = 1.016) times the runoff of Crazy Woman Creek at upper station, near Arvada.

L. Powder River at Arvada Damsite: Runoff was assumed to be that of the gaging station Powder River at Arvada. Recorded runoff at this gaging station was adjusted to the 1970 level development in the MRB 1/ study through September 1963. For this study recorded runoff through September 1970 was adjusted in the same manner as in the MRB framework study.

1/ Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework, Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

M. Powder River above Clear Creek: Runoff was estimated as the drainage area ratio (6360/6050 = 1.051) times the runoff at the Arvada Damsite.

N. Box Elder Creek at Box Elder Damsite: Since this reservoir would be filled by diversion from Piney Creek, runoff of the stream gage Piney Creek at Kearney was used as inflow to Box Elder Reservoir. Continuous records are available from October 1940 to date. October 1938 through September 1940 were taken from Table I-6, Bureau of Reclamation Powder Division Report, Hydrology Appendix.

O. Clear Creek at Lower Clear Creek Damsite: Runoff was assumed to be that of the gaging station Clear Creek near Arvada. Records are available from October 1939 to date. October 1937 through September 1939 was estimated from a correlation with Powder River at Arvada (Figure 4).

P. Powder River at Moorhead Damsite: Runoff was assumed to be the same as for the stream gage Powder River at Moorhead. Recorded runoff for this gaging station was adjusted to the 1970 level of development in the MRB [1/] study through September 1963. Recorded runoff through September 1970 was adjusted in the same manner as in the MRB framework study.

Q. Powder River above Little Powder River: Runoff was estimated as the drainage area ratio (8930/8088 = 1.104) times the runoff at the Moorhead Damsite.

R. Powder River near Locate: Recorded runoff at this gaging station through September was adjusted to 1970 level of development for the MRB [1/] study. For this study, recorded runoff from October 1963 through September 1970 was adjusted in the same manner.

3. Area-capacity curves for the various reservoir sites are shown on Figures 5 through 11.

4. Reservoir evaporation rates were obtained from the 1955 Bureau of Reclamation Powder Division report. Hole-in-the-Wall Reservoir has an evaporation rate of 2.69 feet; 2.57 feet was used for Box Elder Reservoir, while 2.68 feet was used for the remaining reservoir sites.

5. Water years 1939 through 1970 were used as the study period, since this period represents the longest period of runoff records available for all stations used on the Powder River. These records were adjusted to show the 1970 level of development within the basin.

6. Reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Minimum contents for Hole-in-the-Wall, Arvada, and Moorhead were determined by subtracting the active contents from the maximum contents. Active contents for the other reservoirs were determined by using the anticipated sediment inflow as the minimum contents. Reservoir contents used in the study are shown below:

Reservoir	Maximum (Acre-feet)	Active (Acre-feet)	Minimum (Acre-feet)
Arvada	1,255,000	890,000	335,000
Box Elder	54,500	45,800	8,700
Hole-in-the-Wall	55,000	45,000	10,000
Lower Clear Creek	602,000	452,000	150,000
Lower Crazy Woman	450,000	350,000	100,000
Moorhead	1,150,000	275,000	875,000
Pumpkin	1,000,000	416,000	584,000

7. Flood control was not considered in this study.

8. Study criteria:

   A. Water in excess of instream needs could be stored or diverted.

   B. When runoff drops below instream needs, water could not be stored or diverted.

   C. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but releases for instream needs were not considered a project function.

   D. Industrial diversions were provided at a constant rate throughout the year.

   E. No shortages were allowed for industrial diversions.

   F. Because of limited time, new irrigation was not considered in separate water supply studies. Should information be desired for new irrigation, water supply for its development could be taken from the total available water from the basin. Industrial diversion potential would then be reduced by that amount.

RESULTS

Several water supply studies were conducted to determine the maximum possible diversion for industrial uses. All studies were for single reservoir systems. Results of the studies are shown below:

Reservoir	Diversion (Acre-feet)	Minimum Content Obtained (Acre-feet)	Smallest Surplus 1/ (Acre-feet)	Date 2/
Arvada	65,000 6/ 4/	377,000	12,000	Jan 1962
Box Elder	34,000 4/	12,000	3,300	Mar 1962
Hole-in-the-Wall	24,000 5/	10,180	180	Jan 1962
Lower Clear Creek	101,000 3/	151,660	1,660	Jan 1962
Lower Crazy Woman	27,000 6/	106,570	6,570	Jan 1962
Moorhead	77,000 3/ 4/	875,000	0	Jan 1962
Pumpkin	70,000 5/ 4/	584,110	110	Jan 1962

Although these studies considered only diversion for industrial uses, the above results actually indicate the total amount of water available for diversion for any use. When other uses are included, a more detailed analysis would be required.

One operation study was run without any reservoirs and no diversions. Summaries of flow shortages (instream needs less runoff) for each BSFW stream point are shown on Tables 2 through 11 for comparison with other studies that included reservoirs.

Annual stream point summaries for each reservoir study are attached to this memorandum. Summaries are included only for control points at or below reservoir sites. Table numbers for each study are shown below:

Reservoir	Tables
Arvada	12-16
Box Elder	17-20
Hole-in-the-Wall	21-31
Lower Clear Creek	32-35
Lower Crazy Woman	36-42
Moorhead	43-47
Pumpkin	48-53

1/ Minimum content obtained less minimum allowable content.
2/ For study period.
3/ Diversion at Moorhead Reservoir site.
4/ Diversion from reservoir.
5/ Diversion at Pumpkin Reservoir site.
6/ Diversion at Arvada Reservoir site.

A general column explanation is shown immediately prior to the computer summaries. Complete computer printouts of the above studies are in the NGPRP Water Work Group files.

CONCLUSIONS

Up to 101,000 acre-feet of water can be developed annually from the Powder River Basin for some use, assuming a reservoir at the Lower Clear Creek site and diversion at Moorhead. Mainstream storage, Moorhead Reservoir site, could develop about 77,000 acre-feet annually.

David M. Haiston

I concur: John W. King III
Regional Hydrologist

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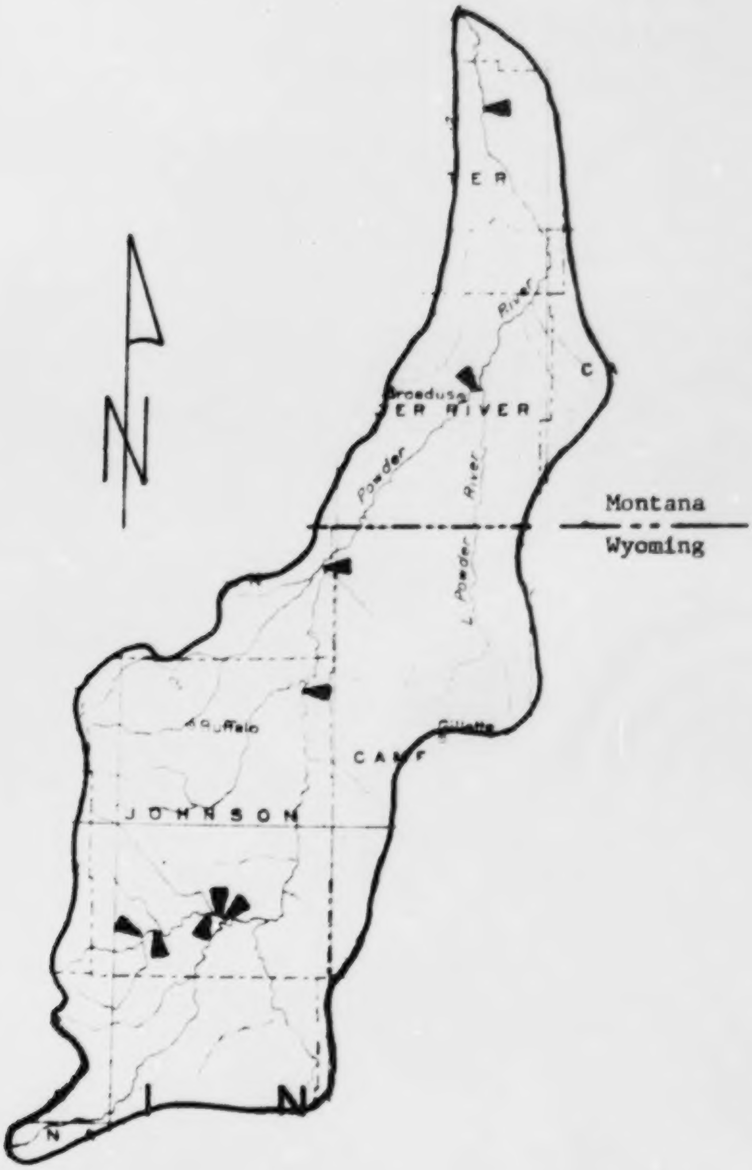
POWDER RIVER BASIN


TER
River
C
Broadus
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Powder
River
L. Powder
Montana
Wyoming
Buffalo
Gillette
CAMP
JOHNSON
N
N

▲ Point of instream water need (BSFW).

Figure 1

Table 1 - Instream Water Needs, Powder River [1/]
(CFS)

Stream Reach	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Above Beaver Creek	4	4	4	6/20	35	35	35/20	9	7	6	4	4
To Red Fork	30	40	40	40	60	60	30	30	30	30	30	30
To North Fork	50	50	50	50	100	100	35	35	35	50	50	50
To Sussex Canal	60	60	60	60	140	140	50	50	50	60	60	60
To South Fork	60	60	60	60	140	100	7	7	7	30	60	60
To Crazy Woman Creek	55	55	85	85	150	105	10	10	9	55	55	55
To Clear Creek	55	55	200	200	270	270	45	12	12	50	55	55
To Little Powder River	100	100	300	300	450	400	120	30	30	100	100	100
To Locate Stream Gage	80	75	400	400	600	600	200	47	40	85	80	80
Crazy Woman Creek at Mouth	5	5	15	15	18	60	10	1	2	5	8	6

[1/] Memorandum of November 20, 1973, to Phil Gibbs from Area Manager, BSFW.

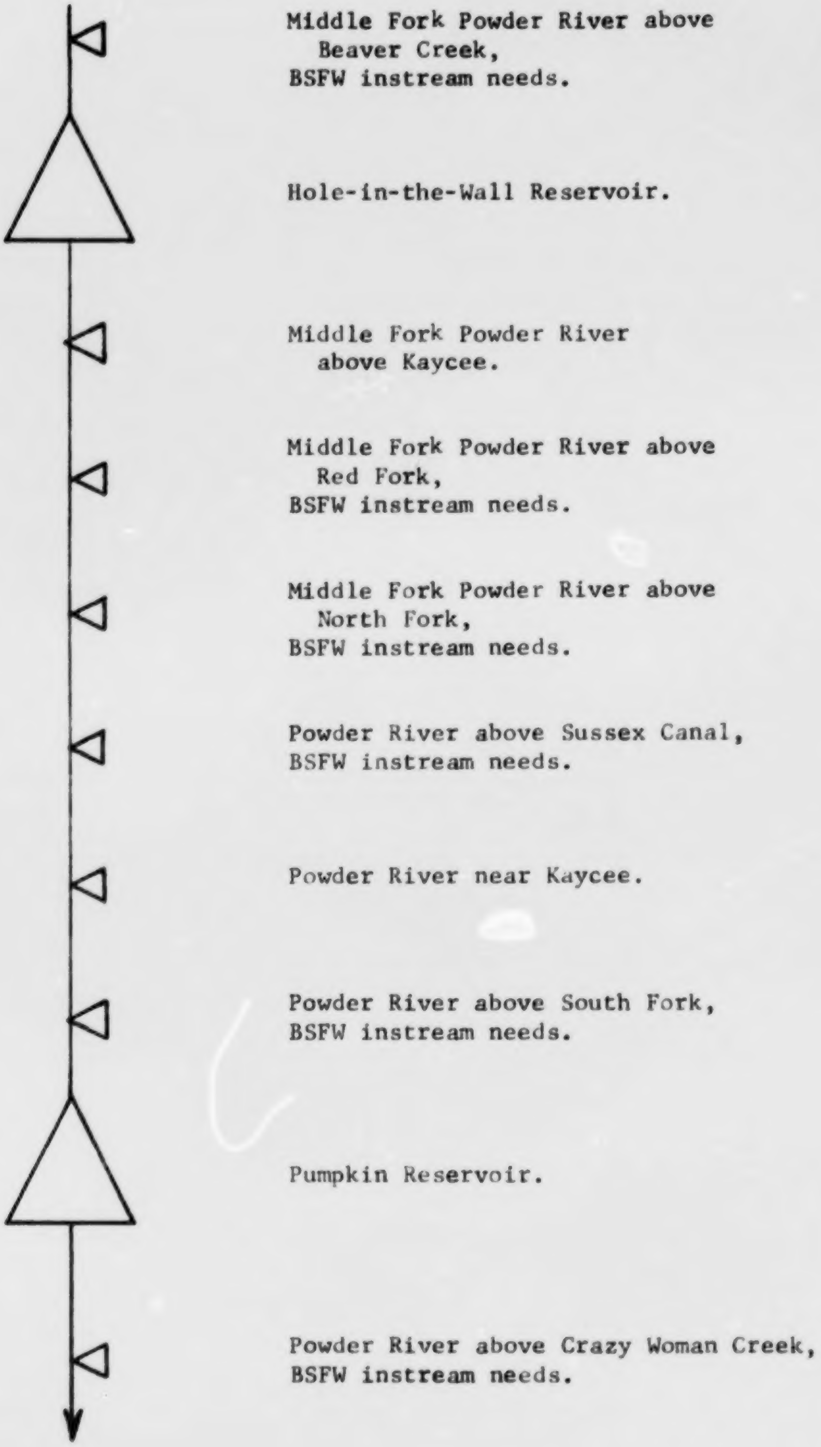
Middle Fork Powder River above Beaver Creek, BSFW instream needs.
Hole-in-the-Wall Reservoir.
Middle Fork Powder River above Kaycee.
Middle Fork Powder River above Red Fork, BSFW instream needs.
Middle Fork Powder River above North Fork, BSFW instream needs.
Powder River above Sussex Canal, BSFW instream needs.
Powder River near Kaycee.
Powder River above South Fork, BSFW instream needs.
Pumpkin Reservoir.
Powder River above Crazy Woman Creek, BSFW instream needs.

Figure 2
Sheet 1 of 2

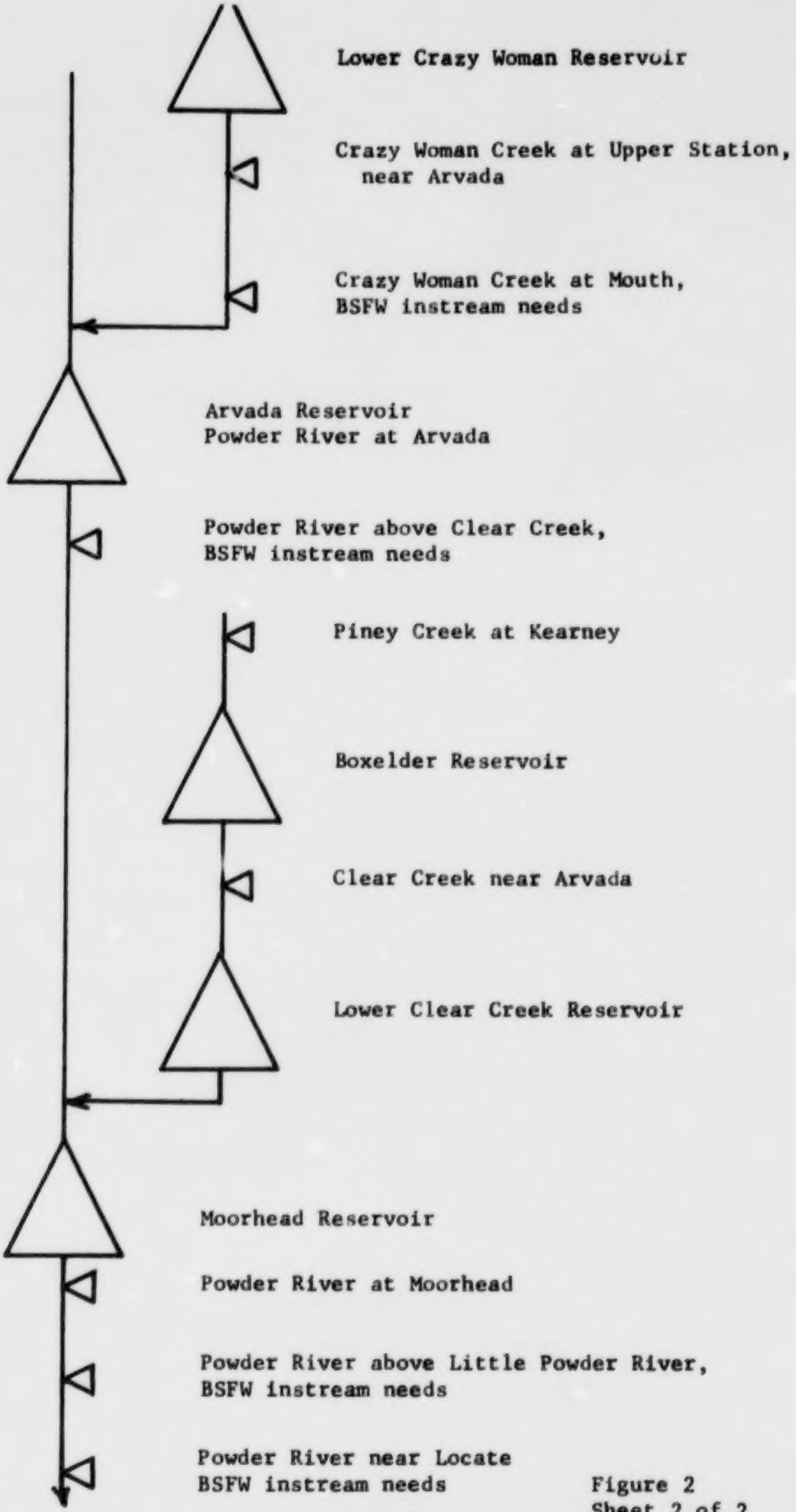
Lower Crazy Woman Reservoir
Crazy Woman Creek at Upper Station, near Arvada
Crazy Woman Creek at Mouth, BSFW instream needs
Arvada Reservoir
Powder River at Arvada
Powder River above Clear Creek, BSFW instream needs
Piney Creek at Kearney
Boxelder Reservoir
Clear Creek near Arvada
Lower Clear Creek Reservoir
Moorhead Reservoir
Powder River at Moorhead
Powder River above Little Powder River, BSFW instream needs
Powder River near Locate
BSFW instream needs

Figure 2
Sheet 2 of 2

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist **DATE:** July 1, 1974

FROM : David M. Haisten

SUBJECT: Water Supply Analysis, Powder River Basin, Northern Great Plains Resource Program (Addendum to memorandum reports dated March 7, 1974, and June 21, 1974)

INTRODUCTION

In reviewing water supply studies for Pumpkin Reservoir on the Powder River, it was discovered that evaporation losses were not considered in the reservoir operation. Therefore, water supply studies for Pumpkin Reservoir were recomputed to make the proper allowances for this consumptive use of water.

PROCEDURE

The same procedures and assumptions, as previously used in water supply studies for the Powder River, were used for this reevaluation of Pumpkin Reservoir. The only change in these procedures was the addition of evaporation losses from the reservoir. Maximum development studies for full BSFW instream water needs criteria and for 10 percent of the BSFW instream water needs criteria were redone. Full computer runs were not made. However, summaries and listings of input are contained in NGPRP files so that full printouts of either study could be obtained in a short period of time.

Reproduced from best available copy.

RESULTS

Results from the revised water supply studies for Pumpkin Reservoir are shown below:

Instream Water Needs Criteria	Industrial Diversion (Acre-feet)
Full	32,000
10%	65,000

CONCLUSIONS

The above results should be used instead of those shown in the memorandum reports of March 7 and June 21, 1974, for Pumpkin Reservoir.

David M. Haisten

I concur: John W. Keys, III
Regional Hydrologist

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5010-108

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : **Regional Hydrologist**

DATE: June 21, 1974

FROM : **David M. Haisten**

SUBJECT: Water Supply Analysis, Little Missouri River, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this study is to analyze the availability of water for development in the Little Missouri River Basin.

The Little Missouri River heads in the plains of northeastern Wyoming, and flows through the northwestern corner of South Dakota into North Dakota. In North Dakota, the Little Missouri River flows north and then east to its confluence with the Missouri River. Major tributaries are the Little Beaver and Beaver creeks, both of which flow from the west. A map showing the Little Missouri River Drainage Basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The program also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

The various data used in the program are shown below with a short discussion as to source, estimates, and assumptions.

1. Instream water needs: Memorandum dated November 29, 1973, to Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings, Montana, From: Area Manager, Bureau of Sport Fisheries and Wildlife, Subject: Northern Great Plains Resource Program - Estimates of Instream Water Needs for the Western Dakota Tributaries. A copy of this memorandum is not attached, but Table 1 summarizes the instream water needs. The point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2. All runoff data reflect 1970 level of development.

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A. Little Missouri River at Camp Cook: Records of runoff are available since June 1956. Runoff data was extended back to October 1938 by correlation with Little Missouri River at Marmarth (correlation shown in NGPRP supporting material) and adjusted to the 1970 level by using information found in the MRB 1/ supporting material.

B. Little Missouri River at Wagon Creek Damsite: Runoff was estimated as the drainage area ratio (((2,245/1,970) = 1.140) times the runoff of Little Missouri River at Camp Cook.

C. Box Elder Creek at Mill Iron Damsite: Runoff was estimated as the drainage area ratio ((920/1,092) = 0.842) times the runoff of Box Elder Creek near Webster (item 2.D.).

D. Box Elder Creek near Webster: Runoff records are available since October 1960. Runoff was extended back to October 1938 by correlation with Little Missouri River at Marmarth (correlation found in NGPRP supporting material) and adjusted to 1970 level by using information found in the MRB 1/ supporting material.

E. Little Missouri River at Marmarth Damsite: Runoff was estimated as the drainage area ratio (3,930/(4,640 - 587) = 0.970) times the difference in runoff between Little Missouri at Marmarth (item 2.G.) and Little Beaver Creek near Marmarth (item 2.F.). This runoff was then adjusted to 1970 level by using information found in the MRB 1/ supporting material.

F. Little Beaver Creek near Marmarth: Records of runoff was available since May 1938. This station was used to estimate the runoff of Little Missouri River at Marmarth Damsite.

G. Little Missouri River at Marmarth: Records of runoff are available since April 1938. Runoff was adjusted to 1970 level from information obtained from the MRB 1/ supporting material.

H. Little Missouri River at Medora Damsite: Runoff was assumed to be the same as Little Missouri River at Medora (item 2.I.).

I. Little Missouri River at Medora: Records are available for the periods May 1903 through October 1908, October and November 1921, March through June and November and December 1922, May 1923 through

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1/ Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

September 1924, September 1928 through September 1934, and October 1945 to date. Runoff for the period October 1938 through September 1945 was estimated by correlation with Little Missouri River at Marmarth (correlation found in NGPRP supporting material). This runoff was then adjusted to 1970 level from information found in MRB[1] supporting material.

J. Beaver Creek at Wibaux: Records are available since May 1938. Runoff was estimated to approximate 1970 level conditions.

K. Beaver Creek at Beaver Damsite: Runoff was estimated as the square root of the drainage area ratio $((610/351)^{0.5} = 1.318)$ times the runoff of Beaver Creek at Wibaux.

L. Little Missouri River near Watford City: 1970 level runoff through water year 1963 was obtained from the MRB[1] report and extended in the same manner through 1970.

3. Area-capacity curves for the various reservoirs investiaged are shown on Figures 3 through 7.

4. Reservoir evaporation rate was estimated to be the same as used for Moorhead Reservoir (1950 Definite Plan Report), 2.68 feet.

5. Water years 1939 through 1970 were used as the study period since these records represent the longest period of runoff records available for all stations used. These records were adjusted to show the 1970 level of development within the basins.

6. Maximum and active reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Minimum contents were determined by taking the difference between the maximum and active contents. Reservoir capacities used in this study are shown below:

Reservoir	Maximum (acre-feet)	Active (acre-feet)	Minimum (acre-feet)
Marmarth	502,000	112,000	390,000
Wagon Creek	230,000	185,000	45,000
Medora	332,000	217,000	115,000
Beaver	89,000	55,200	33,800
Mill Iron	45,000	40,000	5,000

Since minimum contents for Marmarth and Medora reservoirs appear to be higher, other studies were run using 50,000 acre-feet for minimum contents. With the above active contents, the resulting maximum contents were 162,000 acre-feet for Marmarth Reservoir and 267,000 acre-feet for Medora Reservoir.

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7. Flood control was not considered.

8. Study criteria:

   A. Water in excess of instream needs could be stored or diverted.

   B. When runoff drops below instream needs, water could not be stored or diverted.

   C. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases.

   D. Industrial diversions were provided at a constant rate throughout the year. In all studies, the industrial diversions were assumed to occur at the reservoir.

   E. No shortages were allowed for industrial diversions.

   F. No new irrigation.

RESULTS

Results of the various studies are shown below:

Reservoir	Diversion (acre-feet)	Minimum Content Obtained (acre-feet)	Smallest Surplus 1/ (acre-feet)	Date 2/
Medora	45,000 3/	115,510	510	April 1962
	54,000 4/	52,940	2,940	April 1962
Mill Iron	5,000	7,470	2,470	Feb. 1960
Beaver	2,000	33,880	80	March 1965
Marmarth	9,000 3/	392,660	2,660	Feb. 1959
	26,000 4/	52,810	2,810	Feb. 1959
Wagon Creek	25,000	45,760	760	Feb. 1962

1/ Minimum content obtained less minimum allowable content.
2/ Date when minimum content was reached.
3/ Larger minimum contents.
4/ Minimum contents of 50,000 acre-feet.

One run was made with no reservoirs or industrial diversions. Summary tables of flow shortages are shown on Table 2 through 6.

Below is an index of annual summaries for each study:

Reservoir	Tables
Medora (minimum contents = 115,000 AF)	7 - 9
Medora (minimum contents = 50,000 AF)	10 - 12
Mill Iron	13 - 18
Beaver	19 - 21
Marmarth (minimum contents = 390,000 AF)	22 - 26
Marmarth (minimum contents = 50,000 AF)	27 - 31
Wagon Creek	32 - 37

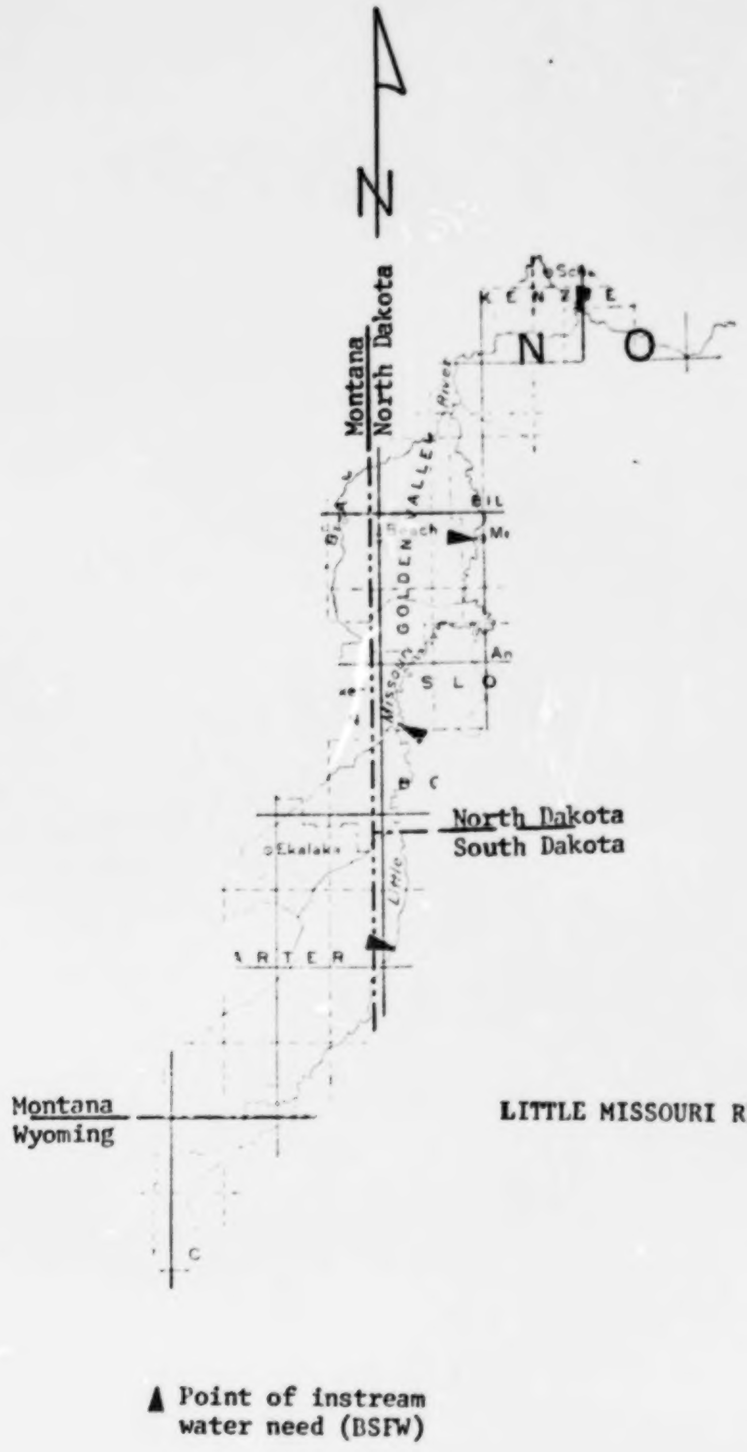
Complete computer printouts of the above studies are in the NGPRP Water Work Group files.

CONCLUSIONS

Up to 54,000 acre-feet of water could be developed from the Little Missouri River for industrial uses and still meet BSFW's instream needs criteria. If other water uses are included, the amount developed would have to be subtracted from the above amount to determine the amount available for industrial uses.

David m. Haisten

I concur: John W.
Regional Hydrologist


N
Montana
North Dakota
K E N Z I E
N O
River
G O L D E N V A L L E Y
B I L
Beach
S L O
Little Missouri
B C
North Dakota
South Dakota
Ekalaka
A R T E R
Montana
Wyoming
▲ Point of instream water need (BSFW)

LITTLE MISSOURI RIVER BASIN

Figure 1

Table 1 - Instream Water Needs, Little Missouri River
(CFS)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Little Missouri River:												
at Camp Cook	4	40	133	95	75	125	44	21	7	7	5	4
at Marmarth	4	160	445	250	196	360	137	47	25	33	20	7
at Medora	2	75	528	370	300	400	180	64	30	29	18	7
near Watford City	1	187	939	497	299	583	270	122	59	68	28	8

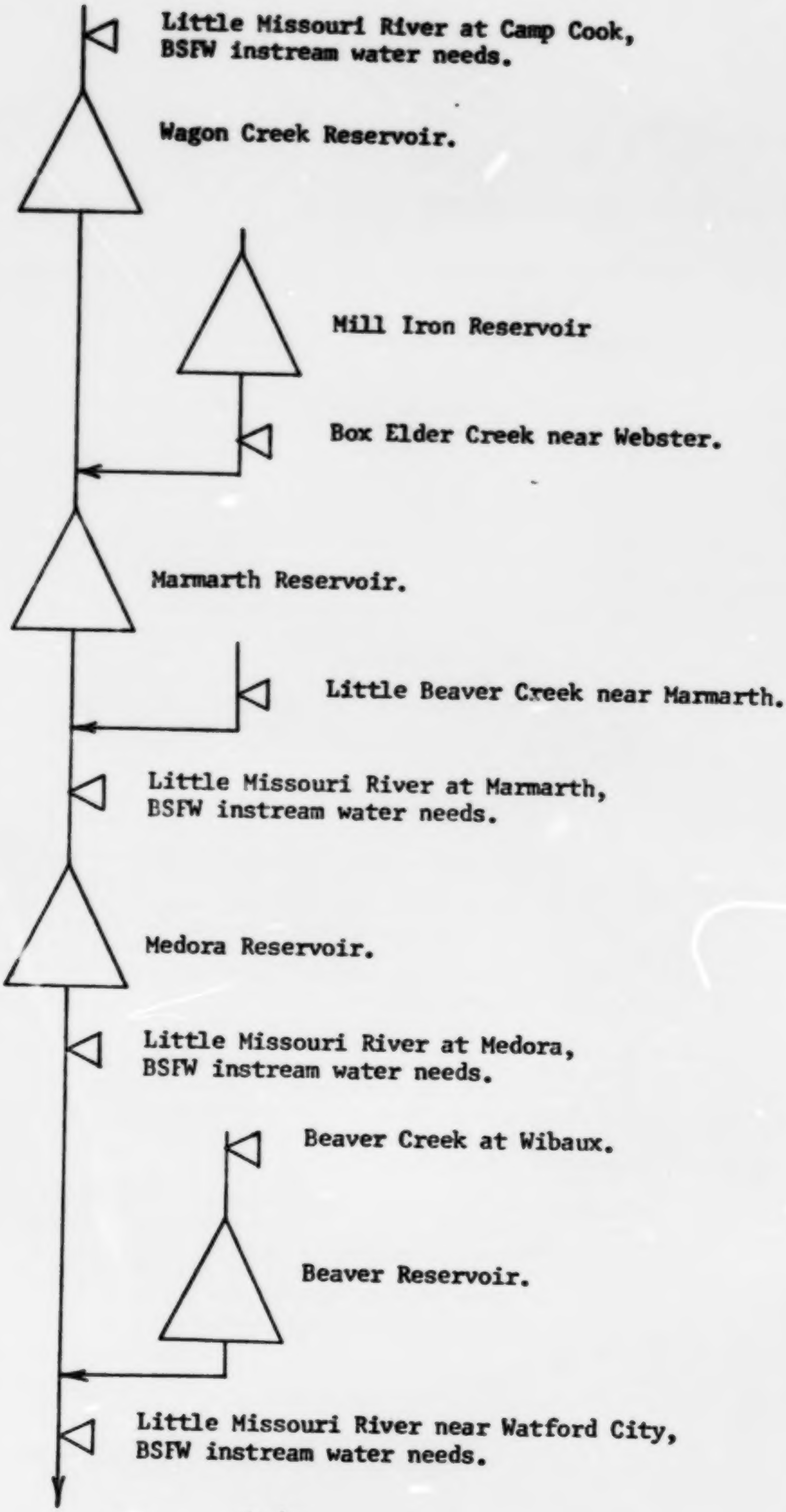

Little Missouri River at Camp Cook,
BSFW instream water needs.
Wagon Creek Reservoir.
Mill Iron Reservoir
Box Elder Creek near Webster.
Marmarth Reservoir.
Little Beaver Creek near Marmarth.
Little Missouri River at Marmarth,
BSFW instream water needs.
Medora Reservoir.
Little Missouri River at Medora,
BSFW instream water needs.
Beaver Creek at Wibaux.
Beaver Reservoir.
Little Missouri River near Watford City,
BSFW instream water needs.

Figure 2

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66

UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: March 8, 1974

FROM : Joseph R. Wensman, David M. Haisten

SUBJECT: Water Supply Analysis, Knife River Basin, North Dakota
Northern Great Plains Resource Program

INTRODUCTION

These studies were conducted to determine the availability of water in the Knife River Basin of western North Dakota for agricultural or industrial development and still meet instream water needs as estimated by the Bureau of Sport Fisheries and Wildlife. Flow regulation was provided by assuming a reservoir at the Broncho Reservoir site which would provide control of approximately half of the Knife River Basin. A copy of the basin description taken from the North Dakota State Water Conservation Commission's Preliminary Draft of Chapter I-VII of an Interim State Water Resources Development Plan is attached as Exhibit I. A map of the drainage basin is shown on Figure 1.

PROCEDURE

The operation studies were conducted on USBR computer facilities using program HYD-2. The model was developed to utilize Bureau of Sport Fisheries and Wildlife instream water needs criteria and provides that the instream water needs, when less than the runoff in the river, are not met directly by reservoir releases. Reservoir releases for downstream diversions may help meet instream needs, but this was not considered a project function.

Broncho Reservoir was assumed to have a total capacity of 305,000 acre-feet with an active capacity of 130,000 acre-feet. This information was obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. The area-capacity curves for Broncho Reservoir are shown on Figure 2.

Estimates of inflow to Broncho Reservoir for 1930 to 1962 were taken from the 1966 USBR report on Knife Division, and flows for 1963 to 1970 were estimated on the same basis as used in the report. Flows at Hazen for 1930 to 1962 were taken from the Missouri River Basin Comprehensive Study and flows for 1963 to 1970 were computed in the same manner.

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Flows at Manning were assumed to be 0.105 of the flow at Hazen based on the ratio of discharges for the period of record at the two sites; flows at Golden Valley were estimated to be 0.493 of the flow at Hazen based on discharge ratios; and the flow at the mouth of the river was estimated to be 1.12 times the flow at Hazen based on drainage area ratios.

Average values for evaporation, irrigation diversion, and return flow were found from the operation studies of the 1966 USBR Knife Division report and are as follows:

Month	Evaporation (AF/Ac)	Irrigation Diversion (AF/Ac)	Return Flow (AF/Ac)
Oct	.20		.09
Nov			.03
Dec			.02
Jan			.02
Feb			.01
Mar			.01
Apr	.10		.01
May	.20	.16	.07
June	.20	.21	.11
July	.40	.84	.19
Aug	.50	.66	.24
Sep	.40	.41	.16
Total	2.00	2.28	.96

Industrial diversions were taken directly from Broncho Reservoir and at a constant year-round rate. When irrigation was considered as a project function, water was diverted from Broncho Reservoir with the return flow occurring above Hazen. The figure of 5,000 acres for irrigation was obtained from the 1973 Missouri River Basin Rate and Repayment Study. For this study, shortages were not allowed for any project function.

The instream water needs determined by the BSFW are as follows:

Month	Instream Water Requirements (CFS)[1] At Manning	 Near Golden Valley	 At Hazen
Oct	2	7	26
Nov	2	9	17
Dec	2	6	19
Jan	1	6	16
Feb	6	27	51
Mar	44	190	316
Apr	55	138	222
May	19	54	53
June	28	83	167
July	21	31	73
Aug	3	14	28
Sep	6	7	25

1/ Memorandum dated November 29, 1973, To: Phil Gibbs, Water Work Group, NGPRP, Bureau of Reclamation, Billings, Montana, From: Area Manager, Bureau of Sport Fisheries and Wildlife, Billings, Montana, Subject: Northern Great Plains Resources Program Estimates of Instream Water Needs for the Western Dakota Tributaries.

A schematic diagram of the Knife River Basin is shown on Figure 3.

RESULTS

Two water supply studies were conducted for the Knife River Basin to determine the maximum possible diversion for industrial uses. The first study considered only industrial diversions of water. The second study considered diversions to both industrial and irrigation water users. The results of these studies are shown below:

Study	Industrial Diversion (Acre-Feet)	Minimum Content Obtained (Acre-Feet)	Smallest Surplus 1/ (Acre-Feet)	Date 2/
1	11,000	180,230	5,230	March 1937
2	2,000	179,560	4,560	March 1937

1/ Minimum content obtained less minimum allowable content.
2/ For 1930-1970 study period.

Annual summaries for the first study are shown on Tables 1 through 6. Annual summaries for the second study are shown on Tables 7 through 12. A column explanation for the operation studies is located at the beginning of the annual summaries. Complete computer printouts of the above studies are included in the NGPRP Water Work Group files.

CONCLUSIONS

About 11,000 acre-feet per year can be developed from Broncho Reservoir for industrial uses and still meet BSFW's instream water needs criteria.

David M. Hairston

I concur: John W. Keys, III
Regional Hydrologist

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Knife River Subbasin

The Knife River rises in the northeastern corner of Billings County and the southeastern corner of McKenzie County. From this point it flows in a tortuous course eastward and slightly southward to the Dunn-Mercer County line, crossing about 15 miles north of the southeast corner of Dunn County. From here it turns and flows eastward and slightly northward to the Missouri River which it enters at Stanton in Mercer County, about 65 miles above Bismarck. The total area of 2,507 square miles drained by the Knife River lies in North Dakota and includes major portions of Dunn and Mercer Counties and lesser portions of Oliver, Billings, Morton and Stark Counties.

A low divide on the west separates the Knife River Basin from the Little Missouri drainage basin. The basin is roughly oval in shape, the greater axis lying approximately east and west and being about 88 miles in length. The greatest width, north and south, is about 40 miles. The river has one important tributary, Spring Creek, which drains about 660 square miles in the northern portion of the basin. One other tributary worthy of note is Antelope Creek which enters the Knife from the north near Hazen.

The Knife River drainage basin lies in that portion of the Great Plains known as the Missouri Plateau. Its topography, for the most part, is rolling, and stream valleys are generally shallow. In the northwestern part of the basin, the steep-sided, mesa-like Killdeer Mountains, with elevations ranging about 3,600 feet above mean sea level, rise to a height of more than 700 feet above the surrounding prairie to form the most conspicuous topographic feature in the watershed.

The Knife River Valley is an alluvial valley varying in width from 1/4 to 2 miles which has been cut into numerous small tracts by the meandering of the stream. The stream channel is narrow and varies in depth from 20 to 35 feet. At many of the bends in the river there are cut banks 100 feet or more in height.

Natural drainage in the subbasin is generally good, with only a few small surface areas containing harmful amounts of alkali. Soils of the subbasin are fertile and well adapted to growing grains when sufficient moisture is available. Sheet and gully erosion affect relatively small areas and are not a serious problem.

Agriculture and livestock raising are the principal industries in the subbasin. There is also some mining of lignite coal which is increasing as a result of the installation of several large thermal generating plants in the area. Some clay is also mined.

Hebron, Beulah, Hazen and Killdeer, with populations in 1960 of 1340, 1318, 1222, and 765 respectively, are the largest towns in the subbasin.

Within the Knife River subbasin, 47 state and locally constructed dams with a minimum individual capacity of 50 acre-feet collectively store 21,358 acre-feet of water, including 1,501 acre-feet for stock water, and 10,573 acre-feet for fish, wildlife and recreation. Small dams and dugouts store an additional 9,284 acre-feet for stock water and incidental fish and wildlife use.

The State Engineer has granted permits for the use of approximately 2,700 acre-feet of subbasin water for irrigation purposes. Except in unusual circumstances, one acre-foot is granted per acre of land to be

Exhibit 1

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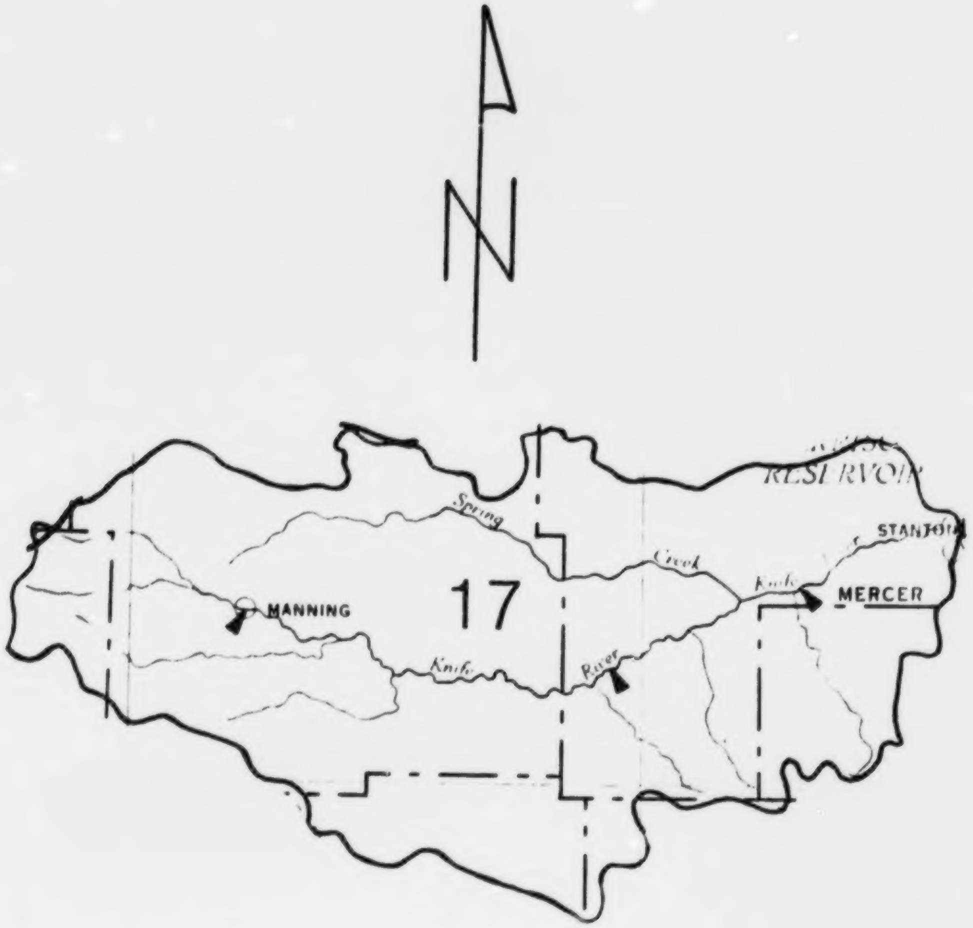
irrigated. Flood control measures in the subbasin are limited to a locally constructed ditch and dike system near Hazen.

Exhibit 1


RESERVOIR
STANTON
Spring
Creek
Knife
MERCER
MANNING
17
Knife
River

KNIFE RIVER BASIN

▲ Point of instream water need (BSFW)

Figure 1

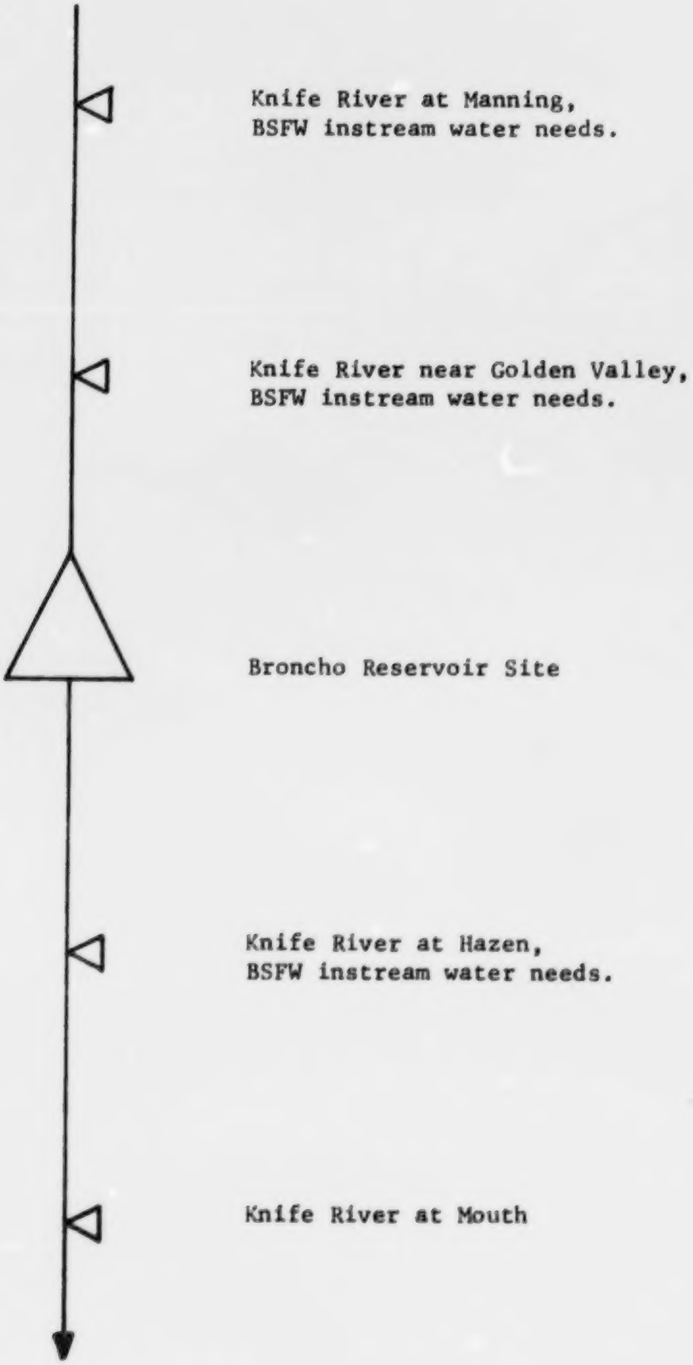

Knife River at Manning,
BSFW instream water needs.
Knife River near Golden Valley,
BSFW instream water needs.
Broncho Reservoir Site
Knife River at Hazen,
BSFW instream water needs.
Knife River at Mouth

Figure 3

OPTIONAL FORM NO. 10
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GSA FPMR (41 CFR) 101-11.6

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UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: June 5, 1974

FROM : David M. Haisten

SUBJECT: Additional Water Supply Analysis, Knife River Basin, North Dakota Northern Great Plains Resource Program (Reference Memorandum date March 8, 1974)

Because of questions raised concerning the large minimum pool for Broncho Reservoir (175,000 acre-feet), the subject water supply studies were recomputed with a minimum pool of 7,000 acre-feet, a normal pool of 130,000 acre-feet, and 175,000 acre-feet for exclusive flood control space. These figures were obtained from a tabulation furnished by the North Dakota Water Commission.

The same procedures and assumptions as used in the March 8, 1974, memorandum report were used with the exception of the above reservoir capacities.

Results of the two studies are shown below:

Industrial Diversion (Acre-feet)	Irrigation (Acres)	Minimum Content Obtained (Acre-feet)	Smallest Surplus 1/ (Acre-feet)	Date 2/
17,000	0	8,910	1,910	March 1937
8,000	5,000	8,910	1,910	March 1937

1/ Minimum content obtained less
Minimum allowable content
2/ For 1930-1970 study period

Annual summaries of these studies are shown on Tables 1 through 12. Complete computer printouts of the operation studies are in the NGPRP Water Work Group files.

CONCLUSIONS

As shown above, about 17,000 acre-feet per year could be developed from Broncho Reservoir for industrial uses.

David M. Haisten

I concur:
Regional Hydrologist

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GSA FPMR (41 CFR) 101-11.6

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UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: June 10, 1974

FROM : David M. Haisten

SUBJECT: Water Supply Analysis, Cannonball River Basin, Northern Great Plains Resource Program.

INTRODUCTION

These studies were done to determine the availability of water in the Cannonball River Basin for future industrial use, while maintaining the minimum streamflows estimated by the Bureau of Sport Fisheries and Wildlife.

The Cannonball River rises in the northeastern corner of Slope County near Amidon, North Dakota, and flows in a southeasterly direction to its confluence with Cedar Creek, its major tributary, on the Grant-Sioux County border. From this point, the Cannonball River flows in a northeasterly course until it enters the Missouri River (Oahe Reservoir) at a point approximately 30 miles above the North Dakota-South Dakota state line. The total area drained by the Cannonball River in North Dakota is approximately 4,310 square miles. Important tributaries in addition to Cedar Creek include Thirty Mile Creek, Dog Tooth Creek, and Louis Creek. A map showing the Cannonball River drainage basin is shown on Figure 1.

PROCEDURE

Water supply studies were conducted on USBR computer facilities using program HYD-2, a general model for computing reservoir operation studies and streamflow management. This program was revised to utilize Bureau of Sport Fisheries and Wildlife's instream water needs criteria. The program also operates reservoirs as well as adjusts runoff for upstream effects upon the quantity of water.

The various data used in the program are shown below with a short discussion as to source, estimates, and assumptions.

1. Instream water needs: Memorandum dated November 29, 1973, To: Phil Gibbs, Water Work Group Chairman, NGPRP, Bureau of Reclamation, Billings, Montana, From: Area Manager, Bureau of Sport Fisheries and Wildlife, Subject: Northern Great Plains Resources Program - Estimates of Instream Water Needs for the Western Dakota Tributaries. A copy of this memorandum is not attached, but Table 1 summarizes the instream water needs. The

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point of each instream need is shown on Figure 1. Flow needs were converted to acre-feet per month for use in water supply studies.

2. Stream point locations for runoff from the basin are shown schematically on Figure 2.

   A. Cannonball River at Regent: Recorded runoff was used.

   B. Cannonball River at Mott Damsite: Runoff was estimated as the drainage area ratio ((689/580) = 1.188) times the runoff of Cannonball River at Regent.

   C. Cannonball River below Bentley: Recorded runoff was used.

   D. Cannonball River at Cannonball Damsite: Runoff was estimated as the drainage area ratio ((1,363/1,140) = 1.196) times the runoff at Cannonball River below Bentley.

   E. Cedar Creek near Haynes: Recorded runoff was used.

   F. Cedar Creek at Thunderhawk Damsite: Runoff was estimated as the drainage area ratio ((1,260/1,340) = 0.940) times the runoff of Cedar Creek near Pretty Rock (item 2.G.).

   G. Cedar Creek near Pretty Rock: Recorded runoff was used.

   H. Cedar Creek near Raleigh: Runoff was estimated as the drainage area ratio ((1,750/1,340) = 1.306) times Cedar Creek near Pretty Rock.

   I. Cannonball River below Confluence: Runoff was estimated as the drainage area ratio ((3,600/4,100) = 0.878) times the runoff of Cannonball River at Breien (item 2.J.).

   J. Cannonball River at Breien: Recorded runoff was used.

3. In order to allow for the 1970 level depletion effect, a diversion of 6,700 acre-feet[1] was made below the confluence of Cedar Creek with the Cannonball River.

4. Area-capacity curves for the three reservoir sites are shown on Figures 3, 4, and 5.

5. Reservoir evaporation rate of 1.90 feet was obtained from the 1953 Bureau of Reclamation report Water Supply Study for Cannonball Division.

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[1] Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966.

6. Water years 1951 through 1970 were used as the study period since these records represent the longest period of runoff records available for all stations on the Cannonball River.

7. Reservoir capacities were obtained from a table prepared by the NGPRP Water Work Group listing all potential storage sites in the Yellowstone and Western Dakota stream basins. Reservoir capacities used in this study are shown below:

Reservoir	Maximum (Acre-feet)	Active (Acre-feet)	Minimum (Acre-feet)
Mott	230,000	223,000	7,000
Cannonball	172,000	170,000	2,000
Thunderhawk	216,000	211,000	5,000

8. Flood control was not considered in this study.

9. Study criteria:

    A. Water in excess of instream needs could be stored or diverted.

    B. When runoff drops below instream needs, water could not be stored or diverted.

    C. Instream water needs, when greater than runoff in the river, were not met directly by reservoir releases. Reservoir releases for downstream diversions could help meet instream needs, but these releases were not considered a project function.

    D. Industrial diversions were provided at a constant rate throughout the year. In all studies, the industrial diversions were assumed to occur at the reservoir.

    E. No shortages were allowed for industrial diversions.

    F. No new irrigation.

RESULTS

Results of the three studies are shown below:

Reservoir	Diversion (Acre-feet)	Minimum Content Obtained (Acre-feet)	Smallest Surplus 1/ (Acre-feet)	Date 2/
Mott	13,000	9,980	2,980	May 1964
Cannonball	22,000	8,450	6,450	May 1964
Thunderhawk	12,000	9,190	4,190	May 1964

1/ Minimum content obtained less minimum allowable content.
2/ Date when minimum content was reached during study period.

One study was run with no industrial diversion or reservoirs. Flow shortages for each streampoint are shown on Tables 2 through 7.

Annual summaries are included in this memorandum for each study. A column explanation for the summaries is included just prior to the summaries.

Below is an index of annual summary tables for each study:

Study	Tables
Mott	8-18
Cannonball	19-29
Thunderhawk	30-40

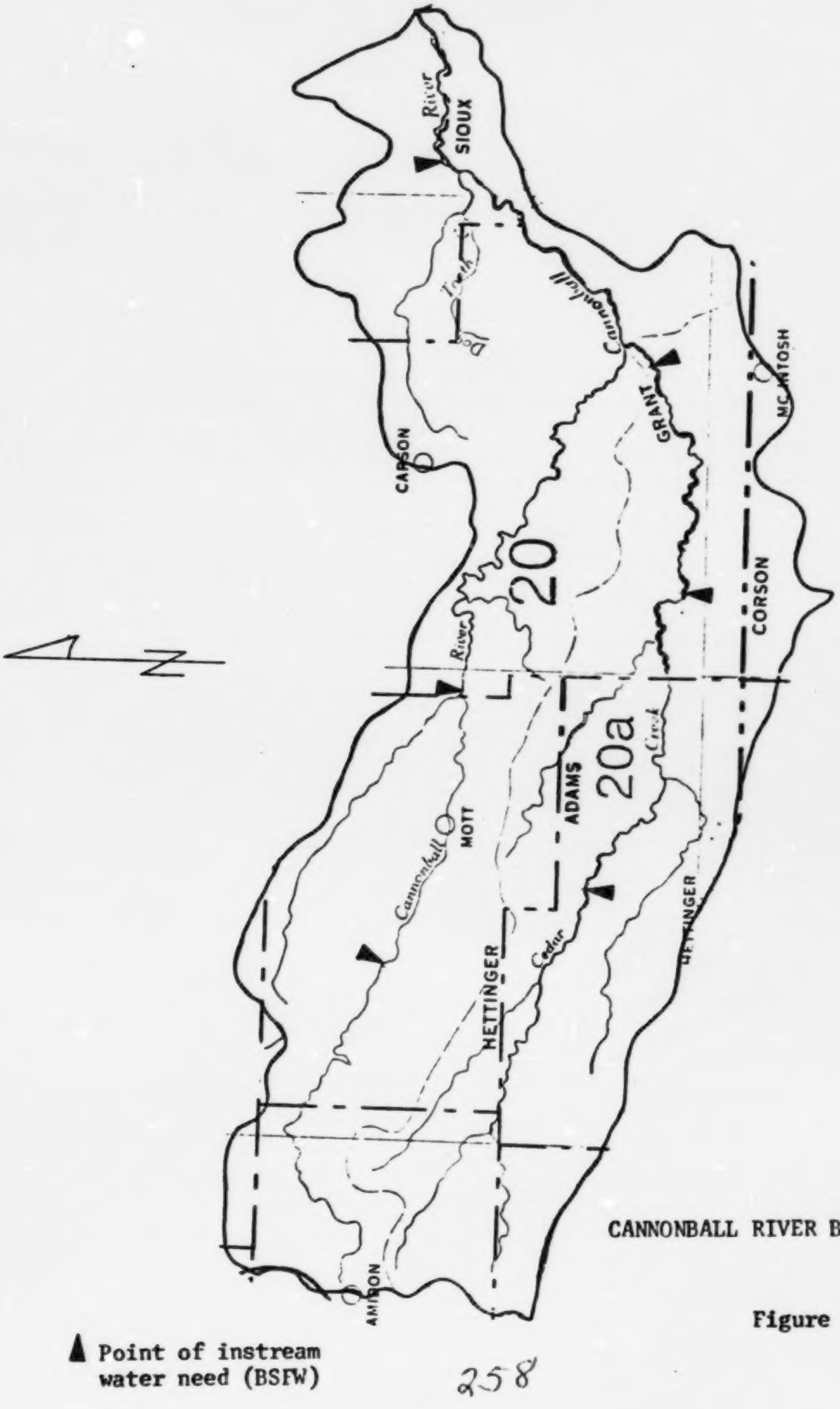
Complete computer printouts of the above studies are in the NGPRP Water Work Group files.

CONCLUSIONS

Up to 22,000 acre-feet of water could be developed for industrial uses in the Cannonball Basin. If water for other uses is also developed, this amount of water would have to be deducted from the total amount available of 22,000 acre-feet.

David M. Haistan

I concur: John W. Keys, III
Regional Hydrologist


River
SIOUX
Dog Tooth
Cannonball
CARSON
GRANT
MC INTOSH
20
CORSON
River
20a
ADAMS
Creek
MOTT
Cannonball
HETTINGER
Cedar
HETTINGER
AMIDON

CANNONBALL RIVER BASIN

Figure 1

▲ Point of instream water need (BSFW)

Table 1 - Instream Water Needs, Cannonball River
(CFS)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cannonball River at Regent	1	5	45	20	20	44	14	6	4	1	3	3
Cannonball River below Bentley	4	15	121	45	47	78	24	11	9	7	9	6
Cedar Creek near Haynes	2	4	33	26	24	51	14	8	2	2	3	2
Cedar Creek near Pretty Rock	2	14	91	72	28	61	22	7	3	2	3	3
Cedar Creek near Raleigh	1	8	95	62	114	96	34	7	9	2	2	3
Cannonball River at Breien	6	39	313	233	129	236	90	25	15	16	18	11

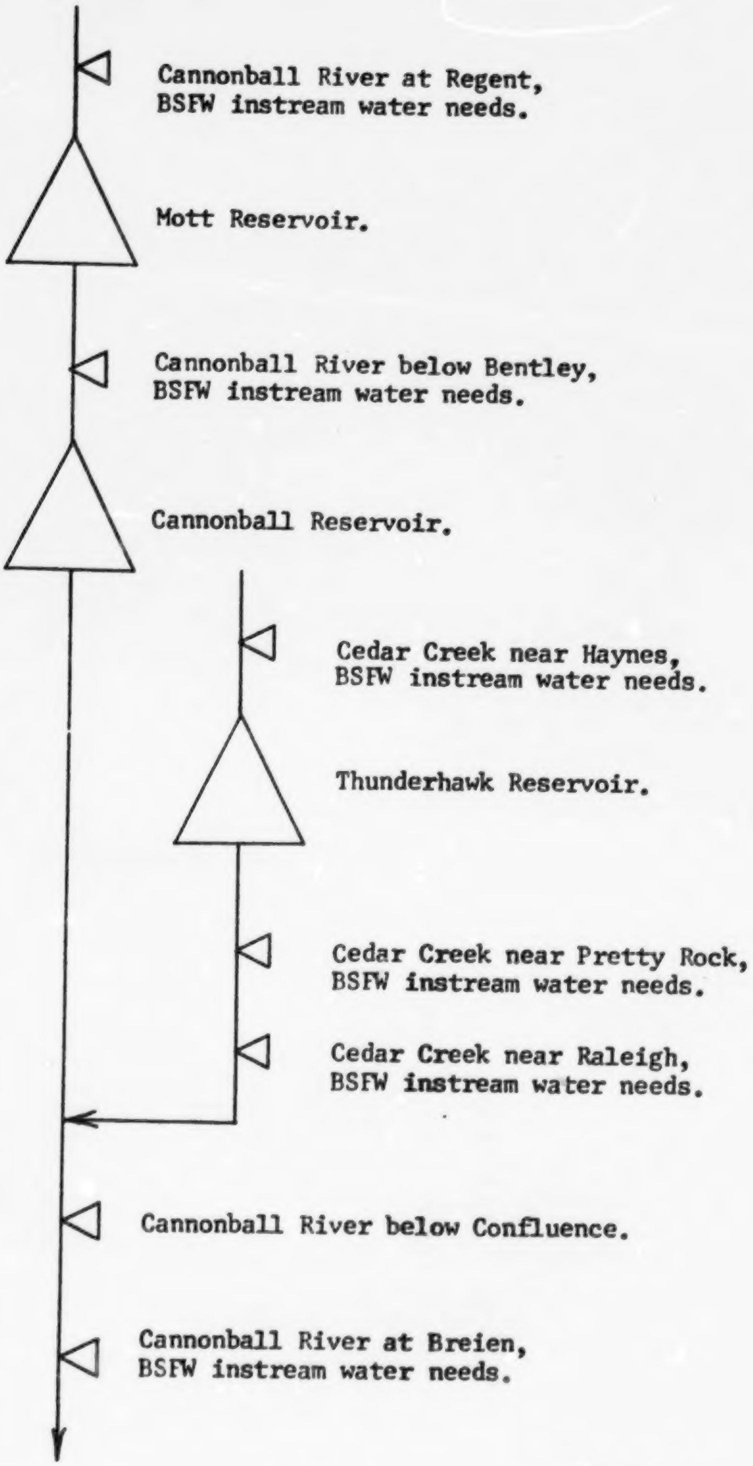

Cannonball River at Regent,
BSFW instream water needs.
Mott Reservoir.
Cannonball River below Bentley,
BSFW instream water needs.
Cannonball Reservoir.
Cedar Creek near Haynes,
BSFW instream water needs.
Thunderhawk Reservoir.
Cedar Creek near Pretty Rock,
BSFW instream water needs.
Cedar Creek near Raleigh,
BSFW instream water needs.
Cannonball River below Confluence.
Cannonball River at Breien,
BSFW instream water needs.

Figure 2

OPTIONAL FORM NO. 10
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UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: June 20, 1974

FROM : David M. Haisten

SUBJECT: Water Supply Analysis, Moreau River Basin, South Dakota, Northern Great Plains Resource Program (Bixby Reservoir)

INTRODUCTION

The purpose of this study is to briefly analyze the availability of water in the Moreau River.

The Moreau River Basin is approximately 180 miles long and 40 miles wide with a drainage area of about 5,700 square miles. Moreau River flows almost due east to its confluence with the Missouri River.

PROCEDURE

The same general methods, procedures and assumptions as used in previous studies in this memorandum series were used. BSFW provided instream water needs at the Faith and Whitehorse stream gages (Table 1). The area-capacity curves for Bixby Reservoir (Figure 1) and evaporation rate of 2.3 acre-feet per acre per year was obtained from the August 1948 Water Supply Study for the Moreau Unit of the Missouri River Basin Project. Bixby Reservoir capacities were obtained from Code 720 and are shown below:

Active Contents	249,200 AF
Minimum Contents	3,800 AF
Maximum Contents	252,000 AF

Records of runoff for a relatively long time are available for the following stream gaging stations on the Moreau River: at Bixby (close to Bixby Damsite), near Faith, and near Whitehorse. The longest common period of record for these stations was used as the study period and includes the years 1955 through 1969.

In order to approximate 1970 level conditions in the operation study, total depletions of 12,700 acre-feet [1] were subtracted from the stream system at the Whitehorse gage as a water right.

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[1] Monthly Streamflow Tables and Depletion Estimates, Missouri River Basin Comprehensive Framework Study, Task Force on Depletions, Work Group on Hydrologic Analyses and Projections, Missouri Basin Inter-Agency Committee, May 1966

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RESULTS

Results of the study for the Moreau River and Bixby Reservoir with no diversion shortages are shown below:

Diversion	Minimum Content Obtained	Surplus 1/	Date 2/
23,000 AF	7,780 AF	3,980 AF	Feb. 1961

1/ Minimum content obtained less minimum allowable content.

2/ Date when minimum content was reached during study period.

Because of the scarcity of data and the level of this study, a full computer run was not made. An annual basin summary and listing of the input data are in the NGPRP Water Work Group files.

CONCLUSIONS

Up to approximately 23,000 acre-feet of water could be developed from the Moreau River at the Bixby Reservoir site annually and still meet BSFW's instream water needs. This water would be available for any beneficial use desired in development of the area.

David M. Haisten

I concur: John W. King, III
Regional Hydrologist

TABLE 1 - Instream Water Needs, Moreau River

(CFS)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Moreau River near Whitehorse	5	5	100	150	150	100	50	20	20	20	10	5
Moreau River near Faith	4	5	30	75	50	30	20	10	10	10	10	5

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UNITED STATES GOVERNMENT

Memorandum

TO : **Regional Hydrologist** DATE: JUN 20 1974

FROM : **David M. Haisten**

SUBJECT: Water Supply Analysis - Grand, Heart, and Platte River Basins, Northern Great Plains Resource Program

INTRODUCTION

The purpose of this memorandum is to review existing reports and current work on the subject river basins and to determine approximate amounts of water available for industrial use. With the probable small amounts of water available in these basins and the abundance of water from other more desirable sources, only a cursory investigation was conducted for these rivers.

DISCUSSION

Grand River Basin

Work now being conducted by our Branch indicates that little or no water could be developed for industrial uses and still meet BSFW instream water needs.

Heart River Basin

Review of the 1971 Bureau of Reclamation's report on the Dickinson Unit, Heart Division, indicates that about 3,000 acre-feet of new water can be developed through enlargement of the existing Edward Arthur Patterson Lake (Dickinson Dam). A tabulation of the historical runoff of the Heart River below Dickinson Dam (Found in the supporting material for the above report) shows an average 1952-1968 runoff of 14,400 acre-feet per year with an annual range of 100 to 43,400 acre-feet. With an annual instream water need determined by the BSFW of nearly 8,200 acre-feet, it appears doubtful that a significant amount of water could be developed for industrial uses.

Platte River Basin

The following information was obtained from the MRB 1/ report:

> ".....The South and North Platte River areas are two in the Missouri River Basin that receive import water, in this case from the Colorado River Basin....."

1/ Missouri River Basin Comprehensive Framework Study, Page 205, Volume 1, Missouri Basin Inter-Agency Committee, June 1969

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With the need to import water from outside the Platte Basin (including the Sweetwater River), it appears that any development for industrial uses is doubtful without further importation of water.

CONCLUSIONS

It is doubtful that any significant amount of water could be developed for industrial uses in the Grand, Heart, and Platte Rivers.

David M. Hairston

I concur: John W. Keys, TF
Regional Hydrologist

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UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist

DATE: June 21, 1974

FROM : David M. Haisten, Hydraulic Engineer

SUBJECT: Water Supply Analysis, Yellowstone River Basin and Western Dakota Tributaries, Northern Great Plains Resource Program (instream water needs at 10%)

INTRODUCTION

The purpose of this study is to analyze the availability of water within the Yellowstone River Basin and Western Dakota tributaries for industrial purposes. Most of the individual streams within the above area were studied using 10 percent of the instream water needs criteria established by the Bureau of Sport Fisheries and Wildlife.

PROCEDURE

The same procedures and assumptions, as used previously in the other memorandum reports in this NGPRP series, were used and will not be repeated here. The only change in criteria was the use of 10 percent of the recommended instream water needs criteria as the flow requirement. The full instream water needs criteria are shown in the other memorandum reports in this NGPRP series and also will not be repeated here. This information will be used for comparative purposes in the NGPRP Water Work Group Report.

Previous studies conducted for the Bighorn River (using storage in Yellowtail Reservoir and considering industrial water options for its water) indicated that about 1.22 million acre-feet of water could be developed annually for industrial uses. To reflect this withdrawal of water from the Bighorn River, two separate sets of studies were conducted for the Yellowstone River (mainstream and offstream) and Clarks Fork Yellowstone River. The first set of these studies considered no diversion of water from the Bighorn River. The second set of these studies considered diversion of 1.22 million acre-feet annually from the Bighorn River on a constant flow basis.

RESULTS

The results of the various studies are shown below:

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River Basin	Reservoirs	Reservoir Capacity [1] (acre-feet)	Annual Diversion of Yellowstone River water with Bighorn River Diversions of: 0 AF (acre-feet)	1.22 M.AF (acre-feet)	Diversion Point [2]
Yellowstone	Offstream				
	Sunday Creek	678,000	3,703,000	2,483,000	1
	Tullock Creek plus above	948,000	3,988,000	2,768,000	1
	Moon Creek plus above	1,098,000	4,145,000	2,925,000	1
	Cedar Creek plus above	1,224,800	4,277,000	3,057,000	1
	Sweeney Creek plus above	1,340,800	4,397,000	3,177,000	1
	Buffalo Creek plus above	1,413,500	4,473,000	3,253,000	1
	Lignite Creek plus above	1,443,500	4,505,000	3,285,000	1
	Mainstream:				
	Allenspur	3,950,000	4,738,000	3,653,000	1
	Lissa	2,180,000	5,161,000	3,941,000	1
Clarks Fork	Hunter Mountain	130,000	2,746,000	1,526,000	1
	Thief Creek	200,000	2,998,000	1,778,000	1
	Sunlight	50,000	2,275,000	1,055,000	1
	All three above	380,000	3,367,000	2,147,000	1
	Baldridge	14,600	1,952,000	732,000	1
	All four reservoirs	394,600	3,389,000	2,169,000	1
	Clarks Fork	750,000	3,573,000	2,353,000	1
	Clarks Fork	512,000	3,304,000	2,084,000	1
Bighorn	Boysen	802,000	431,000 [4]	--	2
	Bighorn Lake	1,116,000	885,000 [4]	--	2
	Bighorn Lake	1,116,000	911,000 [4]	--	3
	Bighorn Lake	1,116,000	2,592,000 [4]	--	8
	Bighorn Lake	1,116,000	2,843,000 [4]	--	1
	Custer	501,000	1,161,000 [4]	--	2
	Custer	825,000	1,271,000 [4]	--	2
Tongue	New Tongue	320,000	159,000	--	2
	Stateline	203,600	119,000	--	2
	Rockwood	113,000	83,000	--	4
	North Prairie Dog	39,900	41,000	--	2
Powder	Arvada	1,255,000	123,000	--	2
	Moorhead	1,150,000	129,000	--	2
	Pumpkin	1,000,000	106,000	--	2

	Clear Creek	602,000	161,000	--	5
	Crazy Woman	450,000	62,000	--	6
	Hole-in-the-Wall	55,000	46,000	--	7
	Boxelder	54,500	34,000	--	2
Little Missouri	Marmarth 2/	502,000	36,000	--	2
	Marmarth 3/	162,000	53,000	--	2
	Medora 2/	332,000	91,000	--	2
	Medora 3/	267,000	100,000	--	2
	Wagon Creek	230,000	34,000	--	2
	Beaver	89,000	2,000	--	2
	Mill Iron	45,000	13,000	--	2
Knife	Broncho 2/	305,000	17,000	--	2
	Broncho 3/	130,000	23,000	--	2
Cannonball	Mott	230,000	21,000	--	2
	Cannonball	172,000	35,000	--	2
	Thunderhawk	216,000	21,000	--	2
Moreau	Bixby	253,000	26,000	--	2

1/ Plus exclusive flood control space if any.

2/ Location of points of diversion:

1 Miles City
2 From reservoir
3 Hardin
4 New Tongue Reservoir site
5 Moorhead Reservoir site
6 Arvada Reservoir site
7 Pumpkin Reservoir site
8 Armells Creek (on Yellowstone River)

2/ Large minimum contents.
3/ Small minimum contents.
4/ With diversion from Boysen Reservoir.

Full computer runs for these studies were not made. Only annual basin summaries are available in the NGPRP Water Work Group files. Listings of the input data are also in the files so that full printouts of any particular study could be obtained in a short period of time.

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CONCLUSIONS

With a reduction in instream water needs, water available for diversion from streams in the Yellowstone Basin could be increased significantly.

David M. Haistan

I concur: John W. Kiger III
Regional Hydrologist

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MAY 1962 EDITION
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UNITED STATES GOVERNMENT

Memorandum

TO : Regional Hydrologist **DATE:** June 18, 1974

FROM : David M. Haisten

SUBJECT: Water Supply Analysis, Yellowstone River Basin and Western Dakota Tributaries, Northern Great Plains Resource Program (Miscellaneous Studies)

INTRODUCTION

The purpose of this memorandum is to present the results of various water supply studies conducted after the individual stream basin memorandum reports had been written. Some of the studies concern combinations of reservoirs; other studies concern a new reservoir site or diversion site.

PROCEDURE

The same procedures and assumptions (with full instream water needs), as used previously in the other memorandum reports in this NGPRP series, were used and will not be repeated here. Runoff at the Lissa Damsite on the Yellowstone River (below the confluence of Bighorn River) was assumed to be the difference between Yellowstone River at Miles City and Tongue River at Miles City.

RESULTS

Table 1 shows the reservoir combinations used for these studies and the resulting water supplies that could be developed from each.

Full computer runs for each study were not made. Only annual basin summaries are available in the NGPRP Water Work Group files. Listings of the input data are also contained in the files so that full printouts of any particular study could be obtained in a short period of time.

CONCLUSIONS

With the addition of one reservoir (Allenspur) to the existing reservoirs of the Yellowstone River system (Boysen and Bighorn Lake), at least 1.7 million acre-feet of water could be developed for any use assuming no diversion shortages. Clarks Fork Reservoir could make about 775,000 acre-feet of water available from Clarks Fork Yellowstone River. With the addition of Custer Reservoir to the Bighorn River system, approximately 536,000 acre-feet of divertable water could be developed.

David M. Haisten

I concur: John W. Keys
Regional Hydrologist

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5010-108

Table 1 - Water Supply Studies Results

Study	Reservoirs	Total Reservoir Capacity[5] (acre-feet)	Industrial Diversion (acre-feet)	Diversion Point
Yellowstone Basin	Boysen	802,000	112,000	Reservoir
	Bighorn Lake	1,116,000	148,000	Reservoir
	Allenspur	3,950,000	1,510,000	Miles City
	Total	5,868,000	1,770,000	
Yellowstone Basin	Boysen	802,000	112,000	Reservoir
	Bighorn Lake	1,116,000	148,000	Reservoir
	Clarks Fork	750,000	680,000	Miles City
	Total	2,668,000	940,000	
Yellowstone Basin	Boysen	802,000	112,000	Reservoir
	Bighorn Lake	1,116,000	148,000	Reservoir
	Clarks Fork[2]	512,000	415,000	Miles City
	Total	2,430,000	675,000	
Yellowstone Basin	Boysen	802,000	112,000	Reservoir
	Bighorn Lake	1,116,000	148,000	Reservoir
	Allenspur	3,950,000	1,722,000	Miles City
	Clarks Fork	512,000	-	
	Total	6,380,000	1,982,000	
Clarks Fork Basin[3]	Clarks Fork [1]	750,000	775,000	Miles City
Clarks Fork Basin[4]	Clarks Fork [1]	750,000	466,000	Miles City
Clarks Fork Basin[3]	Clarks Fork[2]	512,000	520,000	Miles City
Clarks Fork Basin[4]	Clarks Fork[2]	512,000	325,000	Miles City
Bighorn Basin	Boysen	802,000	111,000	Reservoir
	Bighorn Lake	1,116,000	-	Custer
	Custer	825,000	425,000	Reservoir
	Total	2,743,000	536,000	
Bighorn Basin	Boysen	802,000	111,000	Reservoir
	Bighorn Lake	1,116,000	288,000	Armells Creek
	Total	1,918,000	399,000	
Yellowstone Basin	Lissa[3]	2,180,000	1,944,000	Miles City

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1/ Minimum contents = 185,000 acre-feet, letter of May 9, 1974, from Wyoming State Engineer's Office, Subject: Review of Draft Report, Work Group (C) Water, Northern Great Plains Resource Program

2/ Scaled down to elevation 4,500 feet because of high construction cost at 750,000 acre-feet (from Code 720)

3/ Diversion from Bighorn River = 0.AF.

4/ Diversion from Bighorn River = 1,220,000 AF

5/ Plus exclusive flood control.

INSTREAM NEEDS SUBGROUP REPORT

WORK GROUP C WATER

NORTHERN GREAT PLAINS RESOURCE PROGRAM

MAY 1974

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NORTHERN GREAT PLAINS RESOURCE PROGRAM

INSTREAM NEEDS SUBGROUP REPORT

Work Group (C) Water

PREFACE

The task of the Instream Needs Subgroup, Work Group (C) Water, in the NGPRP was to estimate the streamflows needed to sustain the existing aquatic resources and associated wildlife and riparian habitat. The components of the task included: (1) development of a methodology which would roughly estimate instream needs for use in water availability operation studies, and (2) provide a preliminary streamflow estimate which could be evaluated by future detailed biological and water quality studies.

The lead agency for the Instream Needs Subgroup was the U.S. Fish and Wildlife Service. The following page lists the subgroup membership and cooperators.

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NORTHERN GREAT PLAINS RESOURCES PROGRAM
Water Work Group
Instream Needs Subgroup Report

Introduction

Instream water needs were early recognized as one of the more important data inputs required by the Water Workgroup for the NGPRP. An Instream Needs Subgroup was formed to derive the required information. A rapid and cursory review of the literature indicated that several methodologies for determining instream needs had been variously used by several investigators in the United States. However, most of these procedures required extensive collection of field data and were tied to specific objectives and purposes or to specific types of habitat. Other more general methodologies had not been completely developed or were not readily available.

The general lack of detailed biological data relating specifically to streams in the NGPRP area, coupled with severe time constraints which precluded meaningful field observations and collection of field data, necessitated derivation of a "dry-lab" methodology based on existing and reasonably available hydrological records compiled by the USGS. The Bureau of Reclamation was instrumental in formulating a computer program to assimilate the hydrologic data and output the mathematical computations on which eventual instream needs were based. The data so provided were used intoto.

Because of the superficial technique available for deriving instream needs, it should be recognized that the estimates derived are suitable only for the specific purpose intended. More definitive biological and water quality studies must be conducted, including field investigations, before development decisions to be conditioned by instream needs can be made with assurance.

Definition of Instream Flow Needs

Instream water needs were defined, for this study, as the minimum amounts of water required in a stream (seasonally) to maintain essentially the existing aquatic resources and associated wildlife and riparian habitat. Under this definition, the Water Work Group agreed that the instream need estimates would be used to facilitate operation studies designed to determine water availability "unencumbered" by environmental requirements. In this context the instream estimates would act as environmental constraints. The instream estimates were not themselves constrained by legal, institutional, or other non-environmental entities. A basic assumption was that water presently flowing past a recording gage represented the flows supporting present levels of aquatic and related resources. The instream water needs therefore address only quantities of water. It was assumed water quality would remain relatively unchanged.

Methodology

The unit of time selected for analyzing and presenting the instream needs was the calendar month. Biological needs, among others, were considered in selecting the monthly interval.

A shorter time interval is desirable in some cases, but was considered impractical for this study. The existing aquatic community is generally comprised of many species of organisms, each of which have critical periods in their life cycles which must be protected to perpetuate the species. These critical periods can vary throughout the year depending on the species involved. Accordingly, in order to maintain a diverse assemblage of organisms adapted to a given environment, it was decided that the natural hydrologic cycle or pattern of flow should be mimicked. The monthly interval for expressing instream needs will produce this result in a rough manner.

The data base used in the methodology was the existing hydrological surface water records available for a given stream reach. The records show daily flow for each month and are published annually by the USGS. In most water studies, long-term projections of streamflow are based on the past surface water records if the period of record covers an adequate time span. A review of existing records for streams in the Northern Great Plains area indicates that the average monthly flow varies significantly year after year. Therefore, it is expected that similar flow variations will occur in future years. For those years in which the flow for a specific month is extremely low (subnormal) there undoubtedly is a harmful impact to the aquatic resources. However, the unusually wet months (abnormal) are probably not of paramount importance to the overall welfare of the existing aquatic community when considered over a time span of several years. It was therefore assumed that ecosystems are dynamic and influenced by all aspects of the environment, but the more stabilized and representative biological components of an aquatic system are largely supported by a norm or average hydrologic condition rather than by atypical and short-term patterns such as occur during periods of drought and during extremely wet years. On that assumption, the methodology centered on deriving estimates of streamflow needs based primarily on average hydrologic conditions for each specific month and secondly on estimating flow needs for extremely dry periods.

Four successive steps were involved in the derivation of instream need estimates for "average" hydrological conditions. The first step was simply a method that assimilated all the hydrologic data for a given month and indicated which months were to be considered as representative of average conditons. This was determined by using a statistical analysis of the average monthly flows for a specific month over the period of record. Step two involved analysis of the daily flows for the conglomerate "average months" determined in Step one and provided the initial instream estimates of need. These estimates were then adjusted for the non-biological and biological considerations outlined in Step 3 and Step 4, respectively. The final instream estimates of need for average months were the figures

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derived in Step 4.

An additional procedure, Step 5, outlines the concept for handling "dry" months.

All these steps, and the assumptions employed, are discussed in some detail in the following sections in terms of how the data for a specific month, such as August, were analyzed.

Step One

The first step was to assemble all the hydrologic streamflow data available for a given area and segregate the information by month. All of the data pertaining to a specific month for the period of record were then subdivided, on the basis of the average monthly flow, into groupings representing subnormal (dry), average, and abnormal (wet) conditions. Note that if the period of surface water record is 20 years, then the sample size for the month of August is 20.

Delineation based on the variability of the average monthly flow data was thought to be less biased and more representative of actual streamflow conditions than would be simply assigning an inflexible percentage figure above and below the average flow for the period of record to isolate and group the data into subnormal, average, and abnormal categories. The Students "t" statistic was selected for the analysis. (A detailed discussion on the use of this statistic can be found in most standard statistics textbooks). Since the distribution of "t" with an adequate sample size is bell shaped and approaches a normal distribution, an equal number of the average monthly flow values should fall above and below the mean. Theoretically, a large percentage of the individual values will cluster around the mean with fewer and fewer observations occurring with increasing distance from the mean. The objective was therefore to delete those months with average flows falling at a distance from the mean for the period of record. By adding and subtracting the variable $t_x (s) \div \sqrt{n}$ to and from the monthly mean for the period of record, upper and lower limits are established between which are a given percentage of the observations. In the initial testing of this procedure on several stream reaches it appeared that 70 percent of the months should be considered as representing average hydrologic conditions and 30 percent should be deleted. The 30 percent theoretically should be divided equally between subnormal and abnormal months. However, if the data are variable and slightly skewed a larger percentage of below average months, for example, may be deleted and correspondingly fewer above average months. The reverse situation could also be true. Although deviation from normality was common in the delineation, and the use of such a statistic in such cases and in the manner outlined above is questionable, its use as a tool to accomplish the objective appeared to be adequate and representative of the hydrologic conditons for many stream systems and stream reaches studied. Conditions where this procedure could not be used are discussed later.

Step Two

Step two involved compiling the daily flows for each of the "normal months" (as determined by the procedure above), and arraying these from the lowest to the highest. From this array the stream flow exceeded 90 percent of the time was determined and this was considered as the initial (base line) estimate of instream need and is referred to hereafter as the 10 percentile flow. For example, if the number of years in which August was considered "normal" is 20, there would be 620 integrated daily flows arrayed from the lowest to the highest value. If the array was divided into 10 groups, each group would contain 62 values. The first 62 values would represent 10 percent of the data and the last value in this group (62nd value) would be the 10 percentile value flow. The hydrologic data were computerized so that the 10 percentile flow for "normal months" would be displayed.

Selection of the 10 percentile flow was somewhat arbitrary. We assumed that flow is a major controlling factor in an aquatic ecosystem and the lowest flow or flows are more controlling. Generally, however, one day or so at the lowest flow may actually do little harm, but several days at the lowest flow might considerably impair the ecosystem. Under examination the data appeared to support elimination of flows representing the lowest 10 percent of the samples, although this decision must be considered largely as a subjective one.

Assuming daily flows for a specific month are similar year after year, then theoretically, the three lowest flows should be deleted for each "normal" month considered. In reality, similarity in flows year after year holds only to a limited degree. For this reason, the daily flows within the samples were arrayed as previously described and the 10 percentile value subsequently identified. In this manner, the more damaging low flows over the "normal" period were selectively eliminated.

In those sections of stream with an extremely important aquatic resource such as a natural trout stream in a mountainous area or in some of the larger stream systems, streamflow is characteristically much more stabilized during the critical winter and summer months and variation in the daily flows within a month and year after year is much less. It was observed that in such a relatively "flat" flowing stream, the 10 percentile flow for "normal months" is generally not too significantly different from a 20 percentile flow (flow exceeded 20 percent of the time) or in some cases, even a 50 percentile flow (flow exceeded 50 percent of the time) if the entire period of record, without deletion of abnormal and subnormal periods, is used. It was therefore felt that the 10 percentile flow would usually maintain the essential aspects of an aquatic ecosystem at a high level in generally more important areas and at a somewhat lower level in less important areas. This appears reasonable since organisms adapted to more stable systems usually are less tolerant or adaptable to environmental change (such as cold-water fish species) than are those subjected to highly fluctuating systems (such as warm-water fish species in plains streams).

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In the final analysis, selection of the 10 percentile flow can be described as a subjective decision of the fishery specialists examining the hydrology data.

Step Three

In the third step, the instream estimates derived by the analyses outlined above were adjusted to compensate for known quantities of water entering or leaving the stream system within the study reaches. This was necessary because of the criteria used in delineating stream study reaches and the location of gaging stations in relation to the designated reaches. A major stream was divided into several sections with the dividing line between sections generally represented by a major tributary entering the system or a major diversion removing water from the stream. Water was added or subtracted accordingly, where information was available. Since the expressions of instream needs were applied to the downstream boundary of each stream study section, this seemed to be a logical and necessary approach. Delineation of study reaches by this procedure sometimes coincided with major changes in the types of fisheries.

Step Four

The final adjustment (Step four) to finalizing the estimates of instream need for "normal" periods was based largely on knowledge of the types of fishery resources in the study reaches and of specific species requirements. This, in some cases, modified the estimates when there were biological considerations related to patterns in the flow data. However, these adjustments to the values derived by the data analysis in Step Two and adjusted in Step Three were generally of minor significance.

Because fishery data represents the bulk of what is known about the aquatic resources in the study area, many of the adjustments in the calculated estimates focused on this component of the ecosystem, with the general assumption that environmental conditions suitable for fish would also represent the requirements for most of the other aquatic organisms present.

In considering the seasonal pattern of flow, minor adjustments were made in calculated values for ease in handling the data. For example, if the computed instream estimates and subsequent adjustments indicated a flow of 100, 95 and 100 cfs for December, January and February, respectively, the 95 cfs for January was adjusted upward to 100 cfs. If the computed flows were 105, 95 and 100 for the same periods, the first two flows were adjusted to 100 cfs. Decisions on the direction and extent of such adjustments were based on "natural groupings" of several consecutive months.

The same procedure (Steps One through Four) was applied to each of the twelve months. However, the spring runoff period posed a special problem since the presumed seasonal flooding necessary to maintain riparian and associated wildlife habitat is poorly documented for the study area. Also poorly understood are channel flushing requirements to prevent encroachment of vegetation and clean spawning gravels or properly flood other spawning habitat. The freshening effect, which may inititate spawning and other movement of some fish species, is another poorly known requirement. Therefore, we arbitrarily selected a figure near the mean annual flow of record for the high runoff period, assuming from a fisheries standpoint that such flows would generally keep channels open and clean and reasonably maintain spawning conditions for many or most species. This appeared acceptable for the present study, but detailed field studies are essential to determine adequate flow needs during this period. Generally, to a somewhat lesser degree, field studies are essential for all periods of the year.

Step Five

The unusually "dry" months deleted in the statistical analysis, Step One, were treated separately under the assumption that the ecosystem and all other water uses may be seriously impacted when such a condition occurs. Since this happens occasionally as a result of nature, it was decided by the work group that a "sharing" of the shortage would be a logical approach. In these cases, since flow shortages can be broadly predicted as a percentage of normal, it was decided that such predicted percentages should apply to the instream water needs determined for "normal" conditions. However, as discussed in the following section along with other matters, it was necessary to deviate from this procedure because of later developing computer programming difficulties. These particular departures in the way the "dry" month data were handled were for practical reasons and should not be construed as conceptual changes.

Deviations from Methodology

It was considered by some subgroup members that a median, or 50 percentile flow was necessary to assure maintenance of existing trout habitat during the critical stages in the life cycle of some species. This was based on the previous experience and studies of some technicians. This suggestion was adopted. All sections involving natural trout habitat therefore reflect a median or 50 percentile flow requirement (by month) based on average daily flows, and inclusive of all years, high, normal or low. Under this application, all water above the median flow could be stored or diverted, but when the natural flow fell below the estimate of need, then all remaining water must be left in the stream. There were the usual adjustments for tributaries and diversions, as outlined above, and the assumption regarding the spring runoff period also applied. However, there was no adjustment in the flow values to maintain an even flow pattern. Superficial analyses suggested this procedure generally would require little additional water than would have the original methodology.

Another deviation from the methodology involved the Powder River and several western Dakota tributaries. The highly variable runoff

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pattern associated with these streams during the annual cycle and from year to year resulted in extreme skewness in the data and significant departure from a "normal" distribution. As a result, application of the Student's "t" statistic to some months was not practical. Therefore, for these types of streams, but for selected months only, another procedure had to be adopted. Flow in this type of stream system can vary from zero to several thousand cfs within a few days. However, even in these systems, there are often respectable warm water fisheries even though there are some years with short-term periods when water conditions do no more than maintain a few adult brood stock, which, with the return of better conditions, may replenish the fishery. When extended periods of little or no flow severely decimate the fishery, parent streams (such as the Yellowstone) or a reservoir will supply adult fishes to repopulate the decimated stream reach when suitable conditions return. These highly fluctuating stream systems also support riparian-dependent ecosystems for which the water supply must be maintained. These environmental phenomena were considered in deriving the instream estimates for certain months (particularly the late winter and summer periods) for such streams. To deal more effectively with such variable flow conditions, all the available hydrologic data for a given month were divided into groupings based on a percentage of the long term (period of record) mean monthly flow. Four groupings were selected: those months in which the monthly flow averaged less than 10 percent, those months ranging from 10 to 50 percent, those months ranging from 50 to 100 percent and those months exceeding 100 percent of the mean monthly flow for the period of record. For each grouping all the daily flows were integrated and arrayed and an instream flow selected which represented a given percent occurrence. For the dry month grouping (flow less than 10 percent), a 50 percentile or median flow was used as the instream estimate. Even using this relatively high value, in some cases, the estimate of need was zero flow. In these instances, a minimum flow of 1 cfs was substituted after consultation with Bureau of Reclamation hydrologists.

An increasingly lower percentile flow was applied to the other groupings as water conditions improved. However, several problems were encountered in trying to incorporate these different instream flow figures into the computer programmed operation studies. Therefore, it was agreed that a weighted average of the instream need estimates for all groupings would be used in place of the original estimates, for selected stream reaches, in order to facilitate the operation studies. These weighted averages, as used, are presented in the attached tables (footnoted) where applicable, but these values must be viewed with extreme caution. The original instream need estimates for each grouping are on file at the U.S. Fish and Wildlife Service Area Office in Billings, Montana.

These highly fluctuating stream systems are in dire need of detailed biological and water quality studies. They are often considered to be of mediocre importance. However, their contributions to the total ecosystems of adjacent areas and to eventual parent

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watercourses are often of extreme importance in the maintenance of these systems. Among other considerations, habitat essential to important fisheries downstream, terrestrial resources of entire drainages, and to migrating bird life is involved.

Another principal problem encountered was programming the "dry" month data (Step Five, page 8) into the operation studies. Since the predictions of mean monthly flows for "dry" periods would vary, no set percentages of the monthly flow requirements determined for the normal periods could be applied directly to projections of flows expected in dry periods. For example, the expected flow for July in one "low" water year might be 70 percent of "normal", while for the next "low" water year this could be 60 percent. In addition, within a given "low" water year, the projections might be 60 percent of normal for July and 50 percent for August. To incorporate such variable percentages in the computer program would have required manual inputs. Considering almost 40 stream study reaches for up to 12 months in a year, with a variable number of "low" water years possible, this could have necessitated several hundred manual inputs. There were additional related technical problems involved. It was decided that because of the time constraint, all instream needs data would be handled similar to that outlined for trout waters, that is, water could be stored or diverted (in operations studies) above the estimates of need, (determined in Step Four) but when "natural" flows fell below this level, the remaining flows would be left in the streams.

This has several implications considering the assumptions incorporated into the original methodology. First, the methodology would have required some storage releases (where available) for those cases where average monthly flows fell between the lower limit established for "normal" months and the instream estimate of need. For example, where flows between 70 cfs and 120 cfs were considered "normal," average monthly flow was 100 cfs and the 10 percentile flow based on the average daily flow for the composite "normal" months was 85 cfs, then the criteria in the original assumption was that 85 cfs would be maintained in "normal" months including those when flows averaged anywhere from 70 cfs and 85 cfs under natural conditions. This would have extended somewhat, over the period of record, the number of years in which the instream estimate of need (85 cfs) for a specific month would have been maintained. This allowed a kind of trade-off for maintaining existing resources, since minimum flow conditions would be somewhat improved to offset any presumed adverse effects of "skimming" the higher but more variable natural flow for the purpose of storage or diversion. This particular trade-off was lost under the procedure used, thereby suggesting that the estimates of need may require slight adjustment upward to higher flow levels during the critical summer, winter and fall seasons in "normal" periods. Although operation studies were conducted as described, the "original" instream needs under the methodology are shown in the attached tables.

In addition, in "dry" periods (assuming a 50 percent of "normal" month) the flow required under the methodology in the foregoing discussion would have been about 35 cfs (using the lower limit value of 70 cfs for "normal" months). This would have represented a "sharing" of the "shortage," but at a level which, in most cases, would not have had as severe an impact as naturally occurring flows during these periods. The daily flows during the dry months could be fairly normally distributed and range, for example, from 22 to 66 cfs. Under the original assumptions, all of the water above 35 cfs could be stored or diverted, but 35 cfs would be constantly maintained in the stream. Under the subsequent procedure followed, this flow might rarely drop to as low as 22 cfs. It was felt that for the present study this would be acceptable merely to facilitate the operation studies.

At the beginning of the study it was assumed there would be time to evaluate alternative operation studies to analyze a range of environmental impacts by altering the instream regimens and relating these to storage options. Several alternative estimates of instream need were submitted for selected stream reaches but were not analyzed in operation studies because of time constraints. However, the importance of such evaluations should be recognized. The operation studies actually undertaken depict water availability in terms of a given reservoir development or combination of several, with necessary diversions, on a given stream system and using the instream water needs only as a constraint. This constraint was sometimes impinged on by Reclamation personnel conducting the operation studies, and the opportunity to evaluate environmental tradeoffs of altering stream flows and impoundment assumptions did not materialize. This is critically important in considering development alternatives since the study area contains a diversity of aquatic resources and the impacts of reducing or changing streamflows will vary significantly from area to area as will the impacts of alternative storage developments. Water availability could conceivably be increased for areas of lesser importance in order to reduce or prevent impacting an area considered to be extremely valuable.

Summary of Instream Needs

The following tables reflect the instream water needs identified by the Instream Water Subgroup and utilized in the water supply studies (with the modifications noted above). The tables are arranged by basin, beginning with the uppermost stream section and progressing downstream. The estimates indicate only the point above which it was assumed water could be stored or diverted without significant impacts. It is important to note that as a result of the alterations necessary for programming, the instream flows reflected in operation studies would drop below the figures in the tables on some occasions.

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Also included in the tables, for each stream reach in Wyoming and Montana, are estimates of instream need approaching presumed optimum streamflow conditions (these estimates, also by month, are in parentheses). These optimum flow estimates are presented in the context that where water control structures are contemplated, improved stream flows may sometimes be possible for certain stream reaches. These estimates therefore represent rough seasonal "optimums" as target figures. In some cases, however, "optimum" stream flows may be essentially those occurring under natural conditions, as on extremely stable trout streams. In these cases, regulating flows would not significantly improve habitat conditions.

Table 1. Instream Water Estimates (cfs) Tongue River Basin 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Above Highline Diversion	50 (115)	50 (115)	50 (115)	50/100 (115)	200 (200)	200 (200)	200/150 (200/150)	145 2/ (145)	125 2/ (125)	105 2/ (115)	60 (115)	50 (115)
From Highline Diversion to Wolf Creek	50 (115)	50 (115)	50 (115)	55/100 (115)	200 (200)	200 (200)	200/150 (200/150)	125 (125)	105 (125)	95 (115)	60 (115)	50 (115)
From Wolf Creek to Goose Creek	50 (125)	50 (125)	50 (125)	65/100 (125)	200 (200)	200 (200)	200/150 (200/150)	100 (125)	70 (125)	60 (125)	60 (125)	60 (125)
From Goose Creek to Tongue River Reservoir	160 (300)	160 (300)	200 (300)	200/300 (300)	500 (500)	500 (500)	360 (500)	100 (300)	100 (300)	200 (300)	200 (300)	150 (300)
From Tongue River Dam to T&Y Diversion	125 (300)	125 (300)	190 (300)	200 (300)	450 (450)	450 (450)	370 (450)	300 (300)	200 (300)	155 (300)	120 (300)	145 (300)
From T&Y Diversion to Yellowstone River	135 (300)	135 (300)	200 (300)	230 (300)	425 (450)	425 (450)	370 (450)	100 (300)	100 (300)	100 (300)	100 (300)	135 (300)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.

2/ Periods where 50 percentile flows obtained.

Table 1a. Miscellaneous Information and Data Sources used in Deriving Instream Estimates for Tongue River

Stream Reach	Hydrologic Data Gaging Station Number	 Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 1)
Above Highline Diversion	629800	1921-1971	Cold	The average monthly flow diverted to Highline Diversion is included in estimate. Flow estimate for October may need adjustment depending on specific management objectives.
From Highline Diversion to Wolf Creek	629800	1921-1971	Cold	Gaging station location reflects flow diverted to Highline Canal. Flow estimate for October may need adjustment depending on specific management objectives.
From Wolf Creek to Goose Creek	629880 and 6299500	1921-1971 1945-1970	Mixed	The 10 percentile flows for Wolf Creek are included in the estimates.
From Goose Creek to Tongue River Reservoir	6306300	1960-1971	Warm	Estimates include tributary inflow from Goose Creek. Only part of the period of record was computerized at time of analysis.
From Tongue River Dam to T&Y Diversion	6307500	1960-1970	Mixed	Only part of the period of surface water records, since impoundment of Tongue River Reservoir, was computerized at time of analysis. Estimate includes irrigation water for T&Y diversion and therefore represents characteristics in the stream flow regimen associated with storage and operation of the reservoir.
From T&Y Diversion to Yellowstone River	6308500	1960-1971	Warm	Only part of the period of surface water records available for area was computerized at time of analysis. Estimate includes assumption that some return flow would re-enter the Tongue River drainage upstream of the Yellowstone River.

Table 2. Instream Water Estimates (cfs), Powder River Basin 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Buffalo Creek to Beaver Creek	4 (20)	4 (20)	4 (20)	6/20 (20)	35 (35)	35 (35)	35/20 (35)	9 2/ (20)	7 2/ (20)	6 2/ (20)	4 (20)	4 (20)
From Beaver Creek to Red Fork	30 (40)	40 (40)	40 (40)	40 (40)	60 (75)	60 (75)	30 (40)	30 (40)	30 (40)	30 (40)	30 (40)	35 (40)
From Red Fork to North Fork	50 (50)	50 (50)	50 (50)	50 (50)	100 (105)	100 (105)	35 (50)	35 (50)	35 (50)	50 (50)	50 (50)	50 (50)
From North Fork to Sussex Irrigation Canal	60 (70)	60 (70)	60 (70)	60 (70)	140 (145)	140 (145)	50 (70)	50 (70)	50 (70)	60 (70)	60 (70)	60 (70)
From Sussex Irrigation Canal to South Fork	60 (70)	60 (70)	60 (70)	60 (70)	140 (140)	100 3/ (140)	7 3/ (70)	7 3/ (70)	7 3/ (70)	30 (70)	60 (70)	60 (70)
From South Fork to Crazy Woman Creek	55 (75)	55 (75)	85 (85)	85 (85)	150 (175)	105 (175)	10 (75)	10 (75)	9 (75)	55 (75)	55 (75)	55 (75)
From Crazy Woman Creek to Clear Creek	55 (150)	55 (150)	200 (200)	200 (200)	270 (280)	270 (280)	45 3/ (170)	12 3/ (170)	12 3/ (170)	50 3/ (170)	55 (150)	55 (150)
From Clear Creek to Little Powder River	100 (290)	100 (290)	300 (300)	300 (300)	450 (480)	400 (480)	120 (380)	30 3/ (380)	30 3/ (380)	100 (290)	100 (290)	100 (290)
From Little Powder River to Yellowstone River	80 (350)	75 3/ (350)	400 (400)	400 (440)	600 (650)	600 (650)	200 (400)	47 3/ (400)	40 3/ (400)	85 3/ (400)	80 (350)	80 (350)
Crazy Woman Creek from Dry Creek to Mouth 4/	5 (25)	5 (25)	15 (25)	15 (25)	18 3/ (45)	60 3/ (45)	10 3/ (35)	1 3/ (35)	2 3/ (35)	5 3/ (25)	8 3/ (25)	6 3/ (25)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.
2/ Periods where 50 percentile flows obtained.
3/ Weighted average. (see remarks in Table 2a)
4/ Tributary to Powder River.

Table 2a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Powder River

	Hydrologic Data			
Stream Reach	Gaging Station Number	Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 2)
From Buffalo Creek to Beaver Creek	6309200	1960-1970	Cold	This section is inhabited by several species of trout. Estimates may need adjustment since gradient and other physical characteristics of the stream are not known.
From Beaver Creek to Red Fork	6309500	1949-1970	Mixed	Habitat conditions for trout have deteriorated because of large sediment contributions from Beaver Creek.
From Red Fork to North Fork	6309500 & 6310000	1949-1970 1930-1932 & 1950-1953	Warm	The 10 percentile flows were determined for Red Fork (tributary) and included in estimates.
From North Fork to Sussex Irrigation Canal	6309500 6310000 6311500	1949-1970 1930-1932 1950-1953 1940-1970	Warm	The 10 percentile flows were determined for North Fork (tributary) and included in estimates.
From Sussex Irrigation Canal to South Fork	6312500	1941-1970	Warm	Diversion of water to Sussex Irrigation Canal accounted for because of station location. Estimates for June, July, August and September are weighted averages of the percentile analysis used for highly fluctuating systems (dry years would reflect lower values and wet years higher values).
From South Fork to Crazy Woman Creek	6312500 6313000	1941-1970 1951-1969	Warm	The 10 percentile flows were determined for South Fork and included in estimates.
From Crazy Woman to Clear Creek	6317000	1930-1971	Warm	Estimates for July, August, September and October are weighted averages of the percentile analysis used for highly fluctuating systems (dry years would reflect lower values and wet years higher values.)

Table 2a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Powder River (cont'd)

Stream Reach	Hydrologic Data Gaging Station Number	Hydrologic Data Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 2)
From Clear Creek to Little Powder River	6324500	1935-1971	Warm	Estimates for August and September are weighted averages of the percentile analysis used for highly fluctuating systems (dry years would reflect lower values and wet years higher values).
From Little Powder to Yellowstone River	6326500	1937-1971	Warm	Estimates for February, August, September and October are weighted averages of the percentile analysis. Flows during March, April, May and June may need adjustment depending on specific management objectives.
Crazy Woman Creek from Dry Creek to mouth	6361400	1950-1970	Warm	Estimates for May through December are weighted averages of the percentile analysis used for highly fluctuating systems (dry years would reflect lower values and wet years higher values).

Table 3. Instream Water Estimates (cfs), Clarks Fork of the Yellowstone 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Pilot Creek to Crandall Creek	42 2/ (70)	35 2/ (70)	40 2/ (70)	115 2/ (200)	350 (350)	350 (350)	350 (350)	241 2/ (250)	135 2/ (200)	102 2/ (70)	69 2/ (70)	60 2/ (70)
From Crandall Creek to Sunlight Creek	60 2/ (150)	60 2/ (150)	60 2/ (150)	160 2/ (225)	400 (400)	400 (400)	400 (400)	350 2/ (350)	210 2/ (225)	120 2/ (225)	73 2/ (150)	75 2/ (150)
From Sunlight Creek to Dead Indian Creek	80 2/ (240)	80 2/ (240)	80 2/ (240)	188 2/ (240)	470 (600)	525 (600)	525 (600)	433 2/ (450)	270 2/ (360)	168 2/ (360)	104 2/ (240)	100 2/ (240)
From Dead Indian Creek to Pat O'Hara Creek	90 2/ (250)	90 2/ (250)	90 2/ (250)	200 2/ (250)	500 (650)	600 (650)	600 (650)	450 2/ (450)	300 2/ (400)	200 2/ (400)	120 2/ (250)	120 2/ (250)
From Pat O'Hara Creek to Belfry, Mt.	225 2/ (500)	225 2/ (500)	225 2/ (500)	250 (500)	1000 (1000)	1000 (1000)	1000 (1000)	385 (650)	290 2/ (650)	260 2/ (500)	225 (500)	225 (500)
From Belfry, Mt. to Bridger, Mt.	185 (500)	180 (500)	180 (500)	250 (500)	1000 (1000)	1000 (1000)	1000 (1000)	385 (650)	185 (650)	180 (500)	225 (500)	225 (500)
From Bridger, Mt. to Yellowstone River	350 (500)	350 (500)	350 (500)	350 (500)	1000 (1000)	1000 (1000)	1000 (1000)	350 (650)	350 (650)	350 (500)	350 (500)	350 (500)
Sunlight Creek from 3/ Trail Creek to mouth	20 2/ (60)	20 2/ (60)	20 2/ (60)	28 2/ (60)	70 (125)	125 (125)	125 (125)	83 (85)	60 (80)	48 2/ (80)	31 2/ (60)	25 2/ (60)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.
2/ Periods where 50 percentile flows obtained.
3/ Tributary to Clarks Fork.

Table 3a. Miscellaneous Information and Data Sources used in Deriving Instream Estimates for Clarks Fork of the Yellowstone*

Stream Reach	Hydrologic Data Gaging Station Number	Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 3)
From Pilot Creek to Crandall Creek	6205500	1945-1950	Cold	A percentage relationship between the 50 percentile flow and monthly average determined for Sunlight Creek was applied to the monthly averages available for this area. (Record was not considered adequate for analysis using daily flows.) This area is excellent trout habitat.
From Crandall Creek to Sunlight Creek	6206000	1929-1931 1949-1956	Cold	The 50 percentile flows represent the 50 percentile flow for Sunlight Creek adjusted by a factor representing the average flow differential as related to size of drainage area. Entire flow regimen may need adjustment depending on specific management decisions. This area is excellent trout habitat.
From Sunlight Creek to Dead Indian Creek	--	--	Cold	The 50 percentile flows derived for Sunlight Creek are included in estimates.
From Dead Indian Creek to Pat O'Hara Creek	--	--	Cold	The 50 percentile flows derived for Dead Indian Creek are included in estimate. Derivation of flows for Dead Indian Creek was based on the drainage area ratio of this basin and Sunlight Creek basin.
From Pat O'Hara Creek to Belfry, Mt.	6207500	1921-1971	Cold to mixed	This stream reach influenced by an interaction of tributaries and diversions and detailed studies may indicate a need to adjust the flows in the upper reach of this section.
From Belfry, Mt. to Bridger, Mt.	6207500	1921-1970	Warm	Stream affected by heavy sediment loadings during the spring and summer periods.

Table 3a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Clarks Fork of the Yellowstone* (cont'd)

Stream Reach	Hydrologic Data		Type of Habitat	Remarks (Reference To Table 3)
	Gaging Station Number	Approximate Period of Record		
From Bridger, Mt. to Yellowstone River	6208500	1960-1969	Warm	Stream affected by heavy sediment loadings during the spring and summer periods.
Sunlight Creek from Trail Creek to mouth	6206500	1930-1932 1946-1971	Cold	Sunlight Creek is a tributary to Clarks Fork and the only stream in the Upper Clarks Fork Basin with an adequate period of surface water records.

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* Surface water records are extremely limited upstream of Chance, Montana and therefore the estimates need detailed field evaluation.

Table 4. Instream Water Estimates (cfs) Yellowstone River 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Livingston, Mt. to Boulder River	1190 2/ (1600)	1200 2/ (1600)	1260 2/ (1600)	1540 2/ (1600)	4000 (4000)	4000 (4000)	4000 (4000)	3200 (3200)	2100 (2200)	1950 2/ (1950)	1680 2/ (1700)	1400 2/ (1600)
From Boulder River to Stillwater River	1335 2/ (1650)	1335 2/ (1650)	1385 2/ (1650)	1700 2/ (1700)	4600 (4600)	4600 (4600)	4600 (4600)	3390 2/ (3400)	2300 2/ (2300)	2300 2/ (2300)	1870 2/ (1900)	1565 2/ (1650)
From Stillwater River to Clarks Fork River	1600 2/ (2000)	1600 2/ (2000)	1750 2/ (2000)	2000 2/ (2000)	5500 (5500)	5500 (5500)	5500 (5500)	4200 2/ (4200)	2900 2/ (3000)	2800 2/ (3000)	2300 2/ (2300)	1900 2/ (2000)
From Clarks Fork River to Bighorn River	1950 (2500)	1950 (2500)	2100 (2500)	2350 (2500)	7500 (7500)	7500 (7500)	7500 (7500)	3600 (3600)	3200 (3200)	3100 (3100)	2650 (3100)	2250 (2500)
From Bighorn River to Miles City, Mt.	3500 (5000)	3500 (5000)	4200 (5000)	4400 (5000)	10000 (11000)	10000 (11000)	10000 (11000)	5000 (5000)	5000 (5000)	5000 (5000)	4700 (5000)	4400 (5000)
From Miles City, Mt. to lower Yellowstone Canal (Intake)	3600 (5500)	3600 (5500)	4400 (6000)	4600 (6000)	10500 (12000)	10500 (12000)	10500 (12000)	5100 (5500)	5100 (5500)	5100 (5500)	4800 (5500)	4500 (5500)
From Lower Yellow-Stone Canal to Sidney, Mt.	3500 (6000)	3500 (6000)	4400 (6000)	4600 (6000)	10500 (13000)	10500 (13000)	10500 (13000)	4000 (6000)	4000 (6000)	4000 (6000)	4000 (6000)	4000 (6000)
From Sidney, Mt. to Missouri River	3400 (6000)	3500 (6000)	4400 (6000)	4600 (6000)	12000 (13000)	12000 (13000)	12000 (13000)	4000 (7000)	4000 (7000)	4000 (7000)	4000 (7000)	4000 (6000)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.
2/ Periods where 50 percentile flows obtained.

Table 4a. Miscellaneous Information and Data Sources Used in Deriving Estimates for Yellowstone River

	Hydrologic Data			
Stream Reach	Gaging Station Number	Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 4)
From Livingston, Mt. to Boulder River	61925000	1944-1971	Cold	October, November and December estimates may require adjustment depending on specific management objectives. This area is excellent trout habitat.
From Boulder River to Stillwater River	6192500 6-2000	1944-1971 1947-1971	Cold	The 50 percentile flows derived for Boulder River are included in estimate. This area is excellent trout habitat.
From Stillwater River to Clarks Fork River	6192500 6-2000 6-2050	1944-1971 1947-1971 1944-1971	Cold	The 50 percentile flows derived for Stillwater River are included in estimate. Area is good trout habitat.
From Clarks Fork River to Bighorn River	6214500	1928-1971	Mixed to warm	Gage location reflects inflow from Clarks Fork River. However, some adjustments are made for January, February, March, April, November and December so that the flow estimates would be consistent with the combined estimates derived for the Clarks Fork River and for Yellowstone River from the Stillwater to mouth of Clarks Fork. Water in this section is degraded from early spring to late summer by heavy sediment loading from the Clarks Fork River.
From Bighorn River to Miles City, Mt.	6214500	1928-1971	Warm	Estimates derived for the Bighorn River are included in analysis.
From Miles City, Mt. to lower Yellowstone Canal	6309000	1922-1970	Warm	All flow estimates may need adjustment if future management centers on a specific species such as the paddlefish.

Table 4a. Miscellaneous Information and Data Sources Used in Deriving Estimates for Yellowstone River (cont'd)

Stream Reach	Hydrologic Data		Type of Habitat	Remarks (Reference to Table 4)
	Gaging Station Number	Approximate Period of Record		
From Lower Yellowstone Canal to Sidney, Mt.	6309000	1922-1970	Warm	Average diversion (1960-1971) to lower Yellowstone Canal accounted for in estimates. All flow estimates may need adjustment if management centers on a specific species such as the paddlefish.
From Sidney, Mt. to Missouri River	6329500	1944-1971	Warm	Same as above in regards to paddlefish.

Table 5. Instream Estimates (cfs) Little Bighorn River 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Mt-Wy Stateline TO Pass Creek	65 2/ (105)	61 2/ (105)	61 2/ (105)	65 (105)	150 (150)	150 (150)	150 (150)	117 2/ (120)	96 2/ (120)	84 2/ (105)	72 2/ (105)	66 2/ (105)
From Pass Creek to Lodgegrass Creek	100 2/ (120)	110 2/ (120)	113 2/ (120)	125 (150)	200 (200)	200 (200)	130 (150)	106 2/ (150)	107 2/ (150)	128 2/ (120)	122 2/ (120)	108 2/ (120)
From Lodgegrass Creek to Crow Agency, Mt.	100 (160)	100 (160)	100 (160)	125 (200)	270 (270)	270 (270)	125 (200)	70 (200)	70 (200)	100 (160)	100 (160)	100 (160)
From Crow Agency, Mt. to Bighorn River	100 (200)	100 (200)	125 (200)	200 (250)	350 (350)	350 (350)	200 (250)	100 (250)	100 (250)	100 (200)	100 (200)	100 (200)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.
2/ Periods where 50 percentile flows obtained.

Table 5a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Little Bighorn River

Stream Reach	Hydrologic Data Gaging Station Number	 Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 5)
From Mt-Wy State-line to Pass Creek	6289000	1939-1970	Cold	Some adjustments in the flow regimen may be necessary depending on specific management objectives. This area is good quality trout habitat.
From Pass Creek to Lodgegrass Creek	6290500	1939-1971	Cold	Some adjustments in the flow regimen may be necessary depending on specific management objectives. This area is good quality trout habitat.
From Lodgegrass Creek to Crow Agency, Mt.	6293500	1928-1930	Mixed	Flow estimates may need adjustment during certain periods of the year to facilitate movement of brown trout over the Agency Canal Diversion structure.
From Crow Agency, Mt.to Bighorn River	6294000	1960-1971	Warm	Flow estimates may need adjustment during certain periods to facilitate upstream movement of brown trout. Distribution and movement of brown trout in the river is poorly documented.

Table 6. Instream Estimates (cfs) Bighorn River 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Boysen Res. to Kirby Diversion	750 (850)	750 (850)	750 (850)	750 (850)	1000 (1400)	1050 (1400)	1050 (1400)	1050 (1200)	1050 (1200)	775 (850)	750 (850)	750 (850)
From Kirby Diversion to Upper Hanover Canal	750 (850)	750 (850)	750 (850)	750 (850)	975 (1400)	1025 (1400)	1025 (1400)	1025 (1200)	1025 (1200)	750 (850)	750 (850)	750 (850)
From Upper Hanover Canal to Bighorn Canal	650 (850)	650 (850)	650 (850)	650 (850)	800 (1450)	800 (1450)	800 (1450)	800 (1200)	800 (1250)	650 (850)	650 (850)	650 (850)
From Bighorn Canal to Lower Hanover Canal	650 (850)	650 (850)	650 (850)	300 (850)	400 (1450)	400 (1450)	330 (1450)	330 (1250)	330 (1250)	330 (1250)	650 (850)	650 (850)
From Lower Hanover Canal to Manderson,Wy.	650 (850)	650 (850)	650 (850)	460 (850)	610 (1450)	610 (1450)	585 (1450)	575 (1250)	525 (1250)	475 (850)	650 (850)	650 (850)
From Manderson, Wy to to Greybull River	650 (850)	650 (850)	650 (850)	520 (850)	675 (1450)	675 (1450)	665 (1450)	650 (1250)	595 (1250)	530 (850)	650 (850)	650 (850)
From Greybull River to Shell Creek	700 (1000)	700 (1000)	700 (1000)	700 (1000)	900 (1650)	1450 (1650)	700 (1650)	700 (1400)	700 (1400)	700 (1000)	700 (1000)	700 (1000)
From Shell Creek to Yellowtail Reservoir	1000 (1200)	1000 (1200)	1000 (1200)	1000 (1200)	1200 (2000)	1450 (2000)	700 (1500)	700 (1500)	800 (1500)	1000 (1500)	1000 (1200)	1000 (1200)
From Yellowtail Afterbay Dam to Two Leggins Diversion	2000 (2500)	2000 (2500)	2000 (2500)	2000 (2500)	2000 (3500)	3500 (3500)	2000 (3500)	2000 (2500)	2000 (2500)	2000 (2500)	2000 (2500)	2000 (2500)

Table 6. Instream Estimates (cfs) Bighorn River 1/ (cont'd)

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Two Leggins Diversion to Little Bighorn River	2000 (2500)	2000 (2500)	2000 (2500)	2000 (2500)	2000 (3500)	3300 (3500)	1750 (3500)	1750 (2500)	1800 (2500)	1800 (2500)	2000 (2500)	2000 (2500)
From Little Bighorn River to Bighorn Lowline Diversion	2100 (2700)	2100 (2700)	2100 (2700)	2100 (2700)	2300 (3500)	3500 (3500)	1900 (3500)	1900 (2700)	1900 (2700)	1900 (2700)	2100 (2700)	2100 (2700)
From Bighorn Low-line Diversion to Yellowstone River	2100 (2700)	2100 (2700)	2100 (2700)	2100 (2700)	2100 (4000)	3400 (4000)	1800 (4000)	1800 (2700)	1800 (2700)	1850 (2700)	2100 (2700)	2100 (2700)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirement.

Table 6a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Bighorn River

Stream Reach	Hydrologic Data Gaging Station Number	Hydrologic Data Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 6)
From Boysen Reservoir to Kirby Diversion	6259000	1951-1971	Cold	The 50 percentile flow criteria are not applied because of artificially created habitat and stream is subjected to predetermined reservoir operations. Spring flows are not adjusted to those near mean annual for same reasons. A good trout fishery exists in this stream reach.
From Kirby Diversion to Upper Hanover Canal	--	--	Mixed	Estimates are based on those for upstream section. Fifty percent of the average quantity of water diverted to Kirby Canal (1960, 61, 1968-72) is included in estimate as return flow to the system.
From Upper Hanover Canal to Bighorn Canal	--	--	Mixed	Estimates are based on those for upstream section. Fifty percent of the average flow diverted to Upper Hanover Canal (1961-1972) is included in estimate as return flow to the system.
From Bighorn Canal to Lower Hanover Canal	--	--	Warm	Estimates are based on those for upstream section. Average flow diverted to Bighorn Canal (1961-1972) is accounted for in estimate. Return flow from Bighorn Canal is not included because of the short study reach.
From Lower Hanover Canal to Manderson, Wy.	--	--	Warm	Estimates are based on those for upstream section and include a 50 and 33 percent return flow from the Lower Hanover and Bighorn canals, respectively.
From Manderson, WY to Greybull River	--	--	Warm	Estimates are based on those for upstream section and includes a 17 percent return flow from Bighorn Canal.
From Greybull River to Shell River	--	--	Warm	Estimates are based on those for upstream section plus the average flow from Greybull River, 1930-1970(Gaging Station #6277500)

Table 6a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Bighorn River (cont'd)

Stream Reach	Hydrologic Data		Type of Habitat	Remarks (Reference to Table 6)
	Gaging Station Number	Approximate Period of Record		
From Shell Creek to Yellowtail Res.	6279500	1929-1971	Warm	Gaging station location reflects inflow from tributaries, loss of evaporation, diversion, et cetera for entire stream system.
From Yellowtail Afterbay Dam to Two Leggins Diversion	628700	1967-1972	Cold	Estimates are based only on surface water records since stabilization of Yellowtail Reservoir (1967) and account for the average flow diverted to Bighorn Canal since 1967. The 50 percentile criteria are not applied because of artifically created habitat.
From Two Leggins Diversion to Little Bighorn River	--	--	Mixed	Estimates are based on those for upstream section and account for average diversion to Two Leggins Canal (based on maximum irrigable acreage which could be handled by the existing canal system). No return flow is included in estimates.
From Little Bighorn River to Bighorn Lowline Diversion	--	--	Warm	Estimates are based on those for upstream section plus instream flow from Little Bighorn River (Instream estimates derived for Little Bighorn from Crow Agency to mouth).
From Bighorn Lowline Diversion to Yellowstone River	--	--	Warm	Estimates are based on those for upstream section and account for average diversion to the Bighorn Lowline Canal (based on maximum irrigable acreage which could be handled by this canal system). No return flow is included in estimates.

Table 7. Instream Estimates (cfs) Green River, Wyoming from Potential Kendall Reservoir to Fontenelle Reservoir 1/

Stream Reach	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
From Little Twin Creek to New Fork River	120 2/ (200)	120 2/ (200)	120 2/ (200)	170 2/ (200)	550 (550)	550 (550)	550 (500)	550 2/ (550)	310 2/ (310)	185 2/ (200)	150 2/ (200)	130 2/ (200)
From New Fork River to North Piney Creek	440 2/ (500)	460 2/ (500)	535 2/ (500)	1225 2/ (1250)	1600 (1600)	1600 (1600)	1600 (1600)	1200 2/ (1200)	765 2/ (900)	675 2/ (800)	650 2/ (500)	460 2/ (500)
From North Piney Creek to Fontenelle Res.	450 2/ (650)	475 2/ (650)	550 2/ (650)	1250 2/ (1250)	1600 (1600)	1600 (1600)	1600 (1600)	1250 2/ (1250)	800 2/ (900)	700 2/ (800)	670 2/ (670)	480 2/ (650)

1/ Flows approaching optimum are shown in parentheses immediately below minimum monthly requirements.
2/ Periods where 50 percentile flows obtained.

Table 7a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for Green River

Stream Reach	Hydrologic Data Gaging Station Number	Hydrologic Data Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 7)
From Little Twin Creek to New Fork River	9-1885	1961-1971	Cold	Hydrologic data were not computerized for study reach. Estimates were derived by manual calculations and based on last 10 years of surface water records. Data for diversions and inflow from tributaries were not available at time of analysis.
From New Fork River to North Piney Creek	09209400	1961-1971	Cold	Estimates represent the 50 percentile flow for upstream section minus the average monthly flow for North Piney Creek, 1961-1971 (Gaging Station #9205500).
From North Piney Creek to Fontenelle Reservoir	09209400	1961-1971	Mixed	Information on diversions and inflow from tributaries was not available at time of analysis and future studies may indicate the need to subdivide this stream section.

Table 8. Instream Water (cfs) for Selected Rivers in South Dakota*

Stream and Location	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
South Fork of Grand River near Cash, S.D.	3	5	15	20	15	15	10	10	10	10	5	5
Grand River at Shadehill, S.D.	10	10	60	80	80	60	40	20	20	20	20	10
Grand River at Little Eagle, S.D.	20	20	100	150	150	100	60	40	40	20	20	20
North Fork Grand River near White Butte, S.D.	1	3	29	39	43	50	20	4	1	2	4	3
Moreau River near Faith, S.D.	4	5	30	75	50	30	20	10	10	10	10	5
Moreau River near Whitehorse, S.D.	5	5	100	150	150	100	50	20	20	20	10	5
Cheyenne River at Cherry Creek, S.D.	45	155	185	400	500	300	300	300	270	210	160	95
Little Missouri River at Camp Crook, S.D.	4	40	133	95	75	125	44	21	7	7	5	4

* Estimates derived only for areas considered vulnerable to impoundment or diversion.

Table 8a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for South Dakota

	Hydrologic Data			
Stream Reach	Gaging Station Number	Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 8)
South Fork Grand River near Cash, S.D.	6356500	1946-1970	Warm	Estimates may need adjustment depending on specific management objectives.
Grand River at Shadehill, S.D.	6357500	1942-1971	Mixed	Estimates include adjustments in flows since impoundment of Shadehill Reservoir and requirements of fishery downstream of this impoundment.
Grand River at Little Eagle, S.D.	6357800	1957-1970	Warm	Estimates include adjustments to provide minimum winter flows and to maintain nursery and spawning areas for fish from Lake Oahe.
North Fork Grand River near White Butte, S.D.	6355500	1946-1970	Warm	--
Moreau River near Faith, S.D.	6359500	1942-1970	Warm	Estimates include adjustments to provide minimum winter flows, spring spawning flows for fish from Lake Oahe and for sediment transport.
Moreau River near Whitehorse, S.D.	6360500	1953-1970	Warm	Estimates indicate flows required to sustain a fishery and maintain spawning conditions for fish from Lake Oahe.
Cheyenne River at Cherry Creek. S.D.	6439300	1960-1970	Warm	Estimates indicate flows for spring spawning fish from Lake Oahe and for sediment transport.
Little Missouri River at Camp Crook, S.D.	--	--	Warm	--

Table 9. Instream Water (cfs) for Selected Rivers in North Dakota

Stream and Location	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
North Fork Grand River at Haley, N.D.	1	2	45	29	19	35	4	1	1	1	1	1
Cannonball River at Regent, N.D.	1	5	45	20	20	44	14	6	4	1	3	3
Below Bently, N.D.	4	15	121	45	47	78	24	11	9	7	9	6
at Breien, N.D.	6	39	313	233	129	236	90	25	15	16	18	11
Cedar Creek near Haynes, N.D. (Tributary)	2	4	33	26	24	51	14	8	2	2	3	2
Cedar Creek near Pretty Rock, N.D. (Tributary)	2	14	91	72	28	61	22	7	3	2	3	3
Cedar Creek near Raleigh, N.D. (Tributary)	1	8	95	62	114	96	34	7	9	2	2	3
Little Missouri River at Marmarth, N.D.	4	160	445	250	196	360	137	47	25	33	20	7
at Medora, N.D.	2	75	528	370	300	400	180	64	30	29	18	7
near Watford City, N.D.	1	187	939	497	299	583	270	122	59	68	28	8
Knife River at Manning, N.D.	1	6	44	55	19	28	21	3	6	2	2	2
near Golden Valley, N.D.	6	27	190	138	54	83	31	14	7	7	9	6

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Table 9. Instream Water (cfs) for Selected Rivers in North Dakota (cont'd)

Stream and Location	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Knife River												
at Hazen, N.D.	16	51	316	222	53	167	73	28	25	26	27	19
Spring Creek near Zap, N.D. (tributary)	3	13	69	63	22	28	14	5	7	7	7	5
Heart River												
near South Heart, N.D.	1	8	56	25	20	27	5	6	1	1	1	1
below Dickinson Dam, near Dickinson, N.D.	1	1	35	30	14	31	12	6	2	1	1	1
near Richardton, N.D.	3	15	180	97	53	78	42	9	8	6	7	6
below Heart Butte Dam near Glen Ullin, N.D.	23	16	62	157	50	62	67	55	54	47	34	26
near Lark, N.D.	19	23	230	186	57	139	81	67	32	49	39	28
near Mandan, N.D.	13	23	283	243	71	165	96	77	65	55	42	25
Green River near New Hradec, N.D. (tributary)	1	1	42	43	12	11	12	1	1	1	1	1
Green River near Gladstone, N.D. (tributary)	2	7	73	58	13	25	21	4	3	3	4	3

Table 9a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for North Dakota

Stream Reach	Hydrologic Data: Gaging Station Number	Hydrologic Data: Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 9)
North Fork of Grand River at Haley, N.D.	6355000	1907-1917 1945-1970	Warm	--
Cannonball River at Regent, N.D.	6350000	1950-1971	Warm	--
Cannonball River below Bentley, N.D.	6351000	1943-1971	Warm	--
Cannonball River at Breien, N.D.	6354000	1933-1970	Warm	--
Cedar Creek near Haynes, N.D.	6352000	1950-1970	Warm	--
Cedar Creek near Pretty Rock, N.D.	6352500	1942-1970	Warm	--
Cedar Creek near Raleigh, N.D.	6353000	1938 1961-1970	Warm	--
Little Missouri River at Marmarth, N.D.	6335500	1937-1970	Warm	--
Little Missouri River at Medora, N.D.	6336000	1945-1971	Warm	--

Table 9a. Miscellaneous Information and Data Sources Used in Deriving Instream Estimates for North Dakota (cont'd)

Stream Reach	Hydrologic Data Gaging Station Number	 Approximate Period of Record	Type of Habitat	Remarks (Reference to Table 9)
Little Missouri River near Watford City, N.D.	6337000	1934-1970	Warm	--
Heart River near South Heart, N.D.	--	--	Warm	--
Heart River below Dickinson Dam, near Dickinson, N.D.	6344000	1951-1970	Warm	--
Heart River near Richardton, N.D.	--	--	Warm	--
Heart River below Heart Butte Dam near Glen Ullin, N.D.	6346500	1942-1970	Warm	--
Heart River near Lark, N.D.	6348000	1945-1970	Warm	--
Heart River near Mandan, N.D.	6349000	1940-1970	Warm	--
Green River near New Hradec, N.D.	--	--	Warm	--
Green River near Gladstone, N.D.	6345000	1945-1970	Warm	--

Wild and Scenic Rivers-Recreation Appendix

(Report of the Wild and Scenic Rivers-Recreation Subgroup)

Wild and Scenic River-Recreation Appendix

I. Introduction

Projected coal development in the Fort Union formation of the Northern Great Plains Area would require vast quantities of industrial water. Accordingly, water resource projects are being proposed to meet those needs. The purpose of this report is to evaluate the inherent recreation values of those selected rivers where water development could take place, so that any loss or cost in terms of recreation resources will be fully realized before any decisions are made. We have intentionally not taken other uses of the rivers into consideration in this report. Neither have we differentiated between potential and existing recreation values. This report is not necessarily to be considered a wild and scenic river analysis that could result in legislation or other programs within the States. The report should be treated simply as an evaluation that points out inherent values so that these values are known and can be correctly considered in decisions relating to the Northern Great Plains and the existing and proposed mineral and industrial development.

We have evaluated the recreation and aesthetic values of what we have judged to be the principal rivers of the region. The selections were made from size, length, appearance, uniqueness, and aesthetics. Three of the rivers are outside the boundaries of the Northern Great Plains region. Short segments of the Green, Sweetwater, and Clarks Fork have been included in the evaluation because of their great significance and uniqueness to recreation and aesthetics of the region, and, also, because all three may feel the impact of coal and power development.

It should also be pointed out that in the broadest sense, the entire NGPRP region and especially its rivers and streams have recreation resource values. Our selection of stretches of eleven rivers and the lands immediately adjacent to them is an attempt to evaluate this one resource, the rivers, where values for recreation appeared significant and the threat of impact from coal related development high.

Those rivers evaluated include: The Green and Sweetwater Rivers in Wyoming; the Yellowstone River in Montana and North Dakota; the Clarks Fork of the Yellowstone in Wyoming; the Powder and Tongue Rivers through both Wyoming and Montana; the Little Missouri, Heart, Knife, and Cannonball Rivers in North Dakota; and the Grand River in South Dakota. A reconnaissance was made of each river.

II. River Values

Throughout much of the study area, the river and stream courses provide the principal topographic diversity of the region. This diversity may be nothing more than a shallow valley with trees and shrubs along the banks of a meandering stream. Within the study region, the Grand, Knife, Heart and Cannonball Rivers in the Dakotas are this type of river. In all four of these cases, the slow moving, meandering streams develop pronounced valleys as they near the Missouri River. However, these streams and their tributaries provide the most pleasing scenery and aesthetic values that exist in the country for a hundred miles west of the Missouri River in North and South Dakota. To the west, other rivers such as the Powder and Tongue provide beauty through contrast of tree-lined streams among the semi-arid High Plains. In Wyoming the Clarks Fork of the Yellowstone flows through an outstanding canyon. The Clarks Fork, Green, Sweetwater and Upper Yellowstone all maintain excellent trout fisheries which in addition to their scenic values result in their being significant national recreation resources.

The major point is that rivers of the Northern Great Plains Resource Program region regardless of whether they are meandering streams through farmland or raging white water in deep canyons are critical to aesthetics, scenery and outdoor recreation of the region. Often, the focus of activity of both nature and man in the study is on the streams and rivers of the region. This attention results in the importance of water to the northern plains. Of course, the use of the water for irrigation has been critical to wildlife and to agricultural development. But beyond that, the ribbon of green stretching through the plains brings psychological and social values through the aesthetic setting.

It was the rivers of the Great Plains that became the highways of exploration and settlement of the region. Most of the known sites of Indian villages and other Indian culture are found along rivers within the study region. However, scientific knowledge of prehistoric man in the study area is incomplete since archaelogical surveys and salvage of the study area has been confined to water resource development programs, except for chance findings. The historic record of the Northern Great Plains is highlighted by the fur trader and the trapper. Established trading posts were almost always on a river - many on the Missouri itself. Transportation was easier, water and wildlife were abundant. As settlements became established, the river valleys again became the critical areas because of the availability of water for irrigation. Even later roads tended to follow the rivers where it was practical, if for no other reason than the shortest routes between communities being built on the rivers was by a river valley route. Of course, as the railroads crossed the prairies, new towns were established at intervals along the rail lines.

There is another feature of the water courses of the Northern Plains. Much of the wildlife of the region exists there. For recreationists, this means that the stream valleys are the centers for hunting and simply seeing wildlife. One only need travel through the region to be impressed by the numbers and location of deer and many birds along stream courses. Many of the streams have excellent fisheries which serve to form additional attention to the waterways of the region and brings world reputations for some streams. When the benefits and potential benefits of the rivers and streams of the region are evaluated, it is clear that the recreation use of those waterways brings great economic gain to the resident population with little impact to the natural environment of the Great Plains, as the nation knows it. Planning that emphasize recreational values can result in an economic philosophy for the region that would emphasize that the region's streams be maintained for the enhancement of wildlife, aesthetics and recreation. Such a philosophy does not mean that coal or other development is necessarily incompatible with the maintenance of rivers and streams in their natural state. It does mean, however, that planning is necessary to avoid doing irreputable damage to the region's resources. In this case, plans to protect the recreation and aesthetic values of the natural streams and rivers need to be established quickly. Coordinated planning efforts of all concerned, i.e., Federal, State, and local interests, working toward minimizing the areas of conflict of uses need to start immediately. This must be done because the rivers are the major recreation resource of the region and if recreation is to continue as a part of the life of the Northern Plains, the key streams must be preserved in their natural state. Any change in their natural condition should be only in those rare instances where a basic sacrifice is required to allow an equally important regional or national priority to be met.

In order to more adequately describe and identify the major recreation and aesthetic resources of the rivers identified as the region's major rivers, an evaluation form was prepared as well as a rating sheet. Following an on-site trip to each river, the evaluation forms were completed and the forms sent out to subcommittee members, plus a few other knowledgeable people for their addition, deletion, and reactions. Because some of the items are the evaluation sheets appeared less relevant, the form was shortened somewhat to take full advantage of those who contributed to the review of the data and to make the form more succinct. The rating sheet then was created as a one-page summary that could at a glance reveal to the reader the more valuable recreation assets of the river. In the final analysis, a good deal of judgment had to go into placing rivers into national, regional, or local categories. The results of our on-site visits, input by others and by our judgment are presented in Sections III, IV, and V which follow.

III. National Values of the Region's Rivers

The study region contains some streams that have such outstanding natural qualities as to place them in the category of having national values. Heading this group is the Green River from the Green River Lakes to the Fontenelle Reservoir. This segment of the river is largely undisturbed as is the valley through which it flows. The water quality is excellent and the river offers an outstanding fishery. The valley of the Green above Fontenelle offers one of the largest pristine river segments in the nation outside of Alaska. Recreation resources associated with this river range from scenery, to fishing, to river floating, to small and big game hunting.

The major community in the upper basin of the Green is Pinedale. This town of less than 2,000 has become a significant center for recreationists. The Wind River Range with the world famous Bridger Wilderness and major lakes such as Fremont provide an outstanding natural setting for the Green River that already has earned a national reputation as a vacationland. It is difficult to adequately describe the significance and value to the nation of the entire drainage of the Upper Green. It is a treasure that the nation will increasingly cherish in future years.

A second river with qualities of national significance is the Yellowstone from Yellowstone National Park at Gardiner to Pompey's Pillar 40 miles below Billings, Montana. From Gardiner to Livingston, the Yellowstone's fishery is world famous. Below Livingston, the river turns east and becomes the major communication route through central and eastern Montana. Rails and highways detract from the natural setting of this stretch to and beyond Billings but the river continues to have national values. Aesthetic and scenic values of the valley provide this part of Montana with a setting that contribute to the "Big Sky" reputation. The

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recreation values that complement the outstanding scenery make this stretch of the Yellowstone of national importance. Below Pompey's Pillar, the Yellowstone becomes a classic plains river, one that is the focal point for the region through which it flows. This stretch is included in Section IV.

In North Dakota, the Little Missouri flows from south to north through the western part of the State. Through the ages the Little Missouri formed the Badlands, a natural wonderland that has gained fame, starting with Theodore Roosevelt's love for the area. His Elkhorn Ranch lies along the river approximately 25 miles north of the South Unit headquarters of Theodore Roosevelt National Memorial Park. The era of Roosevelt and the Marquis de Mores in the Medora area led to the establishment of the National Memorial Park. The recreation values of the river have grown in recent years. Attendance continues to grow at both units of the park. Float trips are becoming popular during early summer as knowledge of the area grows. Water level is dependent on spring runoff and usually becomes too low for floating in late summer. The river usually carries a heavy sediment load but almost no man-related pollution exists in the water. Compared to better known areas in Wyoming and Montana, the North Dakota badlands are probably little known nationwide. This is because of the remote setting for the unique combination of history along with an outstanding river resource. From its source in Wyoming, through Montana and South Dakota, this river flows through an area which may likely feel the effects of coal exporation and mining. The upper section has many of the outstanding characteristics found in the lower reaches. Any pollution in the upper reaches will also have a direct effect on that segment that is recognized as being of national significance. Like the preceding two rivers discussed and the Clarks Fork, the Little Missouri is a candidate for designation as part of the National Wild or Scenic River System.

The Clarks Fork of the Yellowstone originates in Montana not far from Cooke City. After crossing the Wyoming state line, the river crosses U. S. 212 at the Crandall Creek Bridge and soon goes into one of the most picturesque canyons of the west. It comes out of the canyon only a little over 20 miles downstream but for that distance the Clarks Fork is a classic stream offering important natural and recreation values. Like the preceding rivers this stretch of river should be preserved in its present condition.

IV. Regional Value Rivers

In addition to those rivers considered to have national values, several rivers within the Northern Great Plains Resource Program

In addition to those rivers considered to have national values, several rivers within the Northern Great Plains Resource Program study region have recreation, scenic, and aesthetic values of regional importance. With the expected influx of people for energy related industry, the demand for recreation opportunities will far exceed anything experienced so far in the Northern Plains. Despite conflicting demand for water which is certain to occur, recreation needs can only be met by utilization of rivers such as the Powder, Tongue, the Yellowstone below Pompey's Pillar, and the upper Sweetwater.

The Sweetwater from its source to Chimney Creek (56 miles) is a high quality mountain stream that is rich in the history of South Pass which is best known for the Oregon and Mormon Trails which used the pass as the gateway to the west. Except for fishing pressure, little recreation use has occurred along the Sweetwater despite significant potential. In future years, the South Pass area will see a great increase in recreation pressure.

The Powder and Tongue rise in the Bighorns and flow northward into the Yellowstone in eastern Montana. Both are exotic streams in that they depend mostly on spring runoff from the mountains instead of downstream rains. They are characterized by broad valleys and tree-lined banks, with hay meadows in the lower stretches. Both are typical Great Plains rivers in appearance and water quality with irrigation withdrawals having perhaps the greatest impact on flows and water qualities. In general, they continue to possess most of their natural qualities and are, therefore, valuable in planning for future recreation opportunities. Because of low, warm water, fishing is only fair to occasionally good. Hunting is excellent and the abundance of wildlife makes simply watching birds and animals a pleasing and sometimes exciting experience. Earlier in this report the importance of rivers and valleys to the development of the Great Plains was noted. These two rivers are prime examples of how both wildlife and man have been drawn to the rivers. Both the Powder and Tongue are unique and classic in that sense. Aesthetically, both rivers contribute greatly to the beauty of southern Montana. The recreation potential is largely undeveloped at this time. With almost 100% of the land along the rivers being in private ownership a great deal of planning and cooperation will be needed to fully realize the recreation value of the Powder and Tongue.

The Yellowstone from Gardiner to Pompey's Pillar has been discussed as having recreation values that are of such high quality as to warrant consideration for national designation for wild and scenic

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river status. For the approximate 300 miles to the Missouri River near the Montana-North Dakota border, the Yellowstone flows through the plains of eastern Montana in a broad, picturesque valley. Cultivated lands are the predominate land use on the valley floor. Transportation routes and towns such as Miles City also lie in the valley indicating again that the rivers of the Northern Great Plains are the focal point for man. Wildlife also tend to congregate in the vicinity of the river.

The river is tree-lined and provides a lush pastoral setting in contrast to the dry lands out of the river bottom. Extensive irrigation diversions of course provide the water for the green valley and in doing so the water of the river suffers somewhat in quality. Below Pompey's Pillar the Yellowstone is a warm water fish such as catfish, sauger, walleye, crappie, and sunfish.

This segment of the Yellowstone also has been the central focus of the history of eastern Montana. Through man's history in the region, it has been a transportation route and the white man has chosen the valley as his principal settlement location. The availability of water, flatland, agricultural capability of game and some topographical protection from the climate have worked together to lead man to choose this valley for his place of activity.

V. Local Value Rivers

This portion of the report considers four rivers that flow into the Missouri in the Dakotas. These are the Grand, Cannonball, Heart, and Knife and except for the Missouri, they are the major rivers of this part of the study region. Although they are the largest rivers in this part of the region, they probably are not unique even in the Dakotas. For example, the Moreau in South Dakota has similar characteristics.

All four begin in western North Dakota and gradually settle into shallow valleys as they approach the Missouri Rivers. They flow through an area rich in history for those interested in Indian culture and the days of fur trading, the following settlement and the military posts. In planning for recreation and aesthetic experiences, rivers of this type are important in providing a pleasing setting as well as providing a major resource for hunting and occasional fishing trips.

VI. Constraints

This section of the report presents the major constraints that must be taken into consideration in order to maintain the qualities that make these rivers a unique resource. Some are of natural significance and may qualify for National Wild and Scenic River status, a possibility that should not be foreclosed in order to accomplish only short range benefits. Planning related to the coal based activity should ensure that options remain open for future managers to have some rivers in their natural state as a management strategy. The major constraints to development of the region's rivers include: (1) National Environmental Policy Act, Section 101 - This portion of the law directs decision makers to "create and maintain conditions under which man and nature can exist in productive harmony." More specifically, this section of the law directs that actions assure aesthetically and culturally pleasing surroundings or setting. Another indication of policy direction is that the nation is to attain the widest range of beneficial uses of the environment without degradation of the resource.

NEPA also directs that we preserve an environment which supports a diversity and variety of environmental opportunities and experiences. Again, these mandates stress the importance of saving our options relating to the scenic and recreation values of the rivers of the Northern Great Plains region. (2) Line-of-Sight Values - One of the most important constraints to the maintenance of the scenic and recreation integrity of these selected rivers is the protection of the natural and pastoral setting. Line-of-sight means, for this discussion, the generally narrow or relatively undisturbed portion of the stream valley. Where the valleys are wide, such as the Powder and Yellowstone, the area of importance is the tree line and, at times, the adjoining use area. The objective of this constraint is to set forth those strategic areas adjacent to the rivers that are vital to values that have made them important to the recreation and scenic aspects of their respective areas. These values vary from river to river. For example, the Green River below Green River Lakes lies in a pristine valley that man has not significantly altered. It is the desire to maintain the present high quality of the river and the valley that is the constraint. On the other hand, the Powder River lies mostly in an undistinguished valley, but provides a pleasant pastoral setting in relation to its general setting. The maintenance of this setting, even though it has been greatly changed by man is the constraint. The reasoning is that

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aesthetically and recreationally, the two rivers cited as examples have important values and these values will increase as time passes as along as the streams are preserved in at least as good condition as they are now. (3) Areas of wildlife concentration - A main theme of this report is the fact that wildlife populations tend to congregate along the streams of the study region. Information from the Surface Resources Work Group presents generalized maps of principal wildlife types. From these maps some inconclusive judgments can be drawn. For example, significant populations occur along the Knife, Heart, Cannonball, and Little Missouri in North Dakota. Deer occur commonly along all of the study rivers. Montana's ring-necked pheasant population is concentrated along the Yellowstone and Tongue. The valleys of the Knife, Heart Cannonball and Grand in the Dakotas also are important pheasant areas. (4) Facility constraints - Existing and future recreation resources should be protected. New facilities should avoid river valleys when feasible. Where it is not possible, great care should be exercised in the planning and construction phases. Below are a few examples of construction techniques that should be followed:

1. Power lines - These should be blended into the landscape, should be contoured around hills rather than across the skyline, they should all be placed in corridors, their construction should be done in a manner that minimizes impact on the surfaces such as with helicopters in rough country.

2. Aqueducts - Bury underground where possible and needed. Revegetate slopes if open cut, allow wooden crossings for big game, do not build with steep sides to keep from trapping big game animals, etc.

3. Roads - Minimize cuts, place across rather than parallel to river and adjoining valley.

4. Fences - Blend, minimize roads for construction, design to allow passage of wildlife.

5. Railroads - Also put in corridors, minimize cuts.

6. Powerplant construction - Blend, bury in some cases, locate in good air dispersal area, location on sites where conflicts with other interests are at a minimum and quality or unique resources are not endangered.

7. Establish utility corridors.

(5) Management Constraints - Maintain minimum flows for recreation uses, such as floating and maintain good aquatic variety and population. Recreation carrying capacities need to be determined in the near future for the riverways.

EVALUATION FACTORS

Water Quality

1. Excellent
2. Good
3. Poor

Relative Relief

1. 500' and over
2. 100' to 500'
3. Less than 100'

Vegetative Cover

1. Trees
2. Shrubs
3. Grassland
4. Trees and grass
5. Shrubs and grass
6. Trees and shrubs
7. Cropland
8. Trees, shrubs and grass

Scenic Setting

1. Outstanding
2. Good
3. Not significant

Unique Features

1. Landforms
2. Whitewater
3. Isolated stream
4. Historic sites
5. Archaeologic sites
6. Pristine setting
7. Natural flow
8. Geologic
9. Endangered species present

Land Use

1. Natural area
2. Grazing
3. Dryland crops
4. Irrigation

Streamflow Characteristics

1. High in ---
2. Low in ---
3. Dry in ---
4. Reservor regulated

Wildlife Habitat

(Big Game)	(Small Game)
A-1. Excellent	B-2. Excellent
A-2. Good	B-2 Good
A-3. Poor	B-3 Poor

Major Recreation Uses

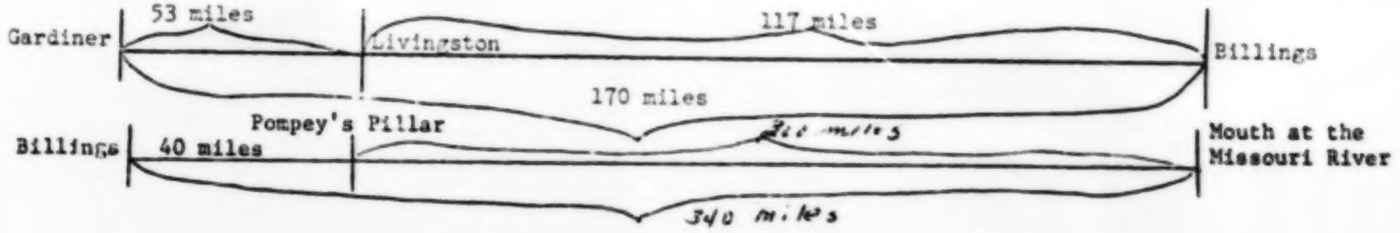
1. Floating
2. Canoeing and kayaking
3. Swimming
4. Fishing
5. Hunting
6. Sightseeing
7. Camping and picnicking
8. Hiking

RIVER EVALUATION FORM

River Yellowstone State(s) Montana County (ies) Park, Sweet Grass, Stillwater, Yellowstone & Carbon, Wibaux, Dawson, Richard, Custer, Prairie, Treasure, Rosebud,

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Gardiner to Livingston	1	3	4	1	1,4,7	2,4	High in May & June	A-1 B-1	4,1,5,6,7
Livingston to Billings	1	3	8,7	2	4	4,2	High In May & June Irrigation	A-2, B-1	6,5,4,7,1
	..						Diversion		
Billings to Mouth	2,3	3	8,7	2	4	4	Diverted for Irrigation	A-2, B-2	5,6,4,1

Remarks:


Gardiner
53 miles
Livingston
117 miles
Billings
170 miles
Billings
40 miles
Pompey's Pillar
300 miles
Mouth at the Missouri River
340 miles

RIVER EVALUATION FORM

River Knife, Heart, Cannonball, Grand
State(s) North Dakota South Dakota
County (ies) NA

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Includes Major Stretches of all Rivers	3	3	4	2	4,5	1,2,3	Low in Late Summer	A-1, B-2	1,2,5,6

Remarks:

RIVER EVALUATION FORM

River Tongue River

State(s) Wyoming and Montana

County (ies) Sheridan, Wyoming
Bighorn, Rosebud
& Custer, Montana

Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
	River Values								
Entire Stretch	1	1 - 2	4 - 6	1 - 2	1, 3	1,2	1. Spring-High 2. Late Summer thru winter-Low	A-1 B-2	2,4,5,6,7,8

Remarks:

Dayton, Wyoming — Miles City, Montana

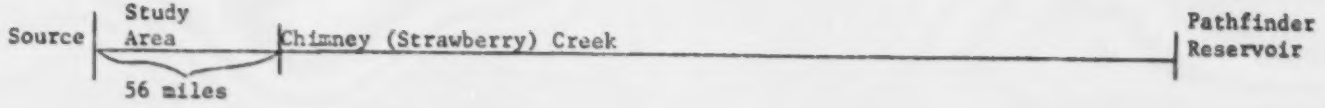
237 miles

RIVER EVALUATION FORM

River Sweetwater State(s) Wyoming County (ies) Fremont

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Source to Chimney Creek	1	3	1 (upper reach) 5 (lower reach)	2	3,7	1,2	Low in Sept.	A-1 B-1	4, 5

Remarks:


Source
Study Area
56 miles
Chimney (Strawberry) Creek
Pathfinder Reservoir

RIVER EVALUATION FORM

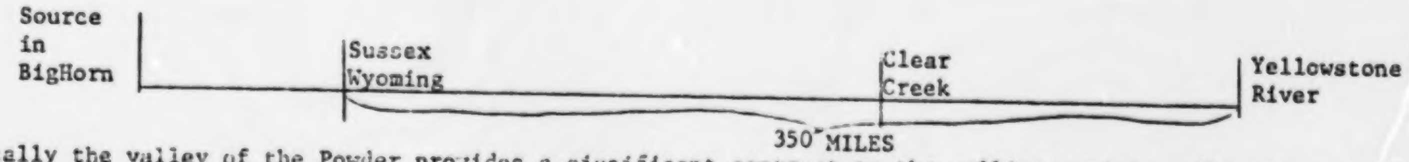
River Powder

State(s) Wyoming, Montana

County (ies) Prairie, Montana
Powder River, Mont.
Custer, Montana
Johnson, Sheridan &
Campbell, Wyoming

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Sussex to Clear Creek	3	3	4	2	none	2,4	Nearly dry during July, Aug &Sept.	A-2, B-2	5,4
Clear Creek to Mouth	3	3	4	2	none	2,4	Controlled by Storage & Diversions	A-2, B-2	5,4

Remarks:



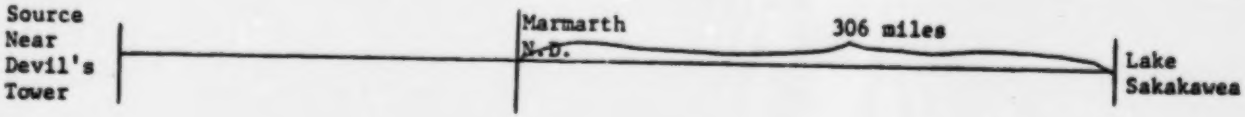
Aesthetically the valley of the Powder provides a significant contrast to the rolling prairie. The presence of water has drawn man and wildlife to the valley. The treelined river and the green of irrigated crops are the keys in this instance of the river values.

RIVER EVALUATION FORM

River Little Missouri State(s) North Dakota County (ies) Slope, Billings, McKenzie, Dunn

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Marmarth to Mouth	2	2	8.7	1	3,4,6,7,8,9	1,4	High in spring	A-1, B-1	1,6,5

Remarks:

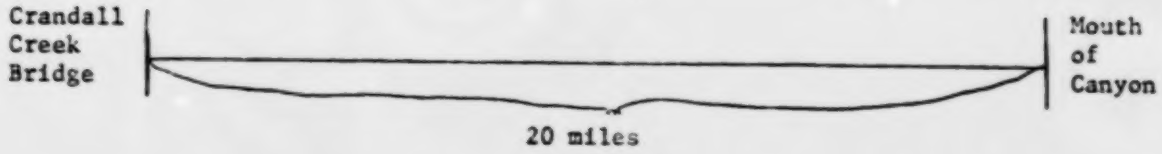

Source
Near
Devil's
Tower
Marmarth
N.D.
306 miles
Lake
Sakakawea

RIVER EVALUATION FORM

River Clarks Fork State(s) Wyoming County (ies) Park

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Entire Stretch	2	1	6	1	1,2,3,6,4,5	1	High in May, June, & July	A-1,B-2	4,5,8,7,6

Remarks:

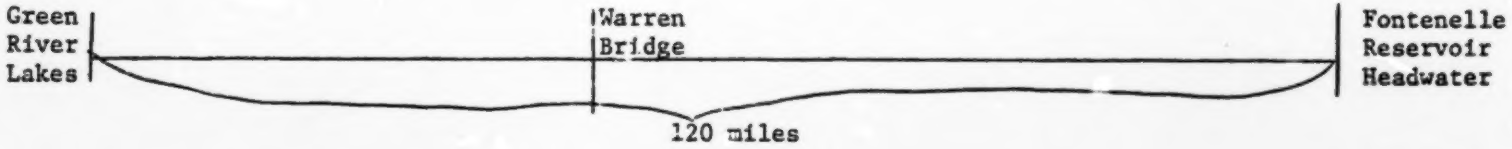

Crandall Creek Bridge
Mouth of Canyon
20 miles

RIVER EVALUATION FORM

River Green River State(s) Wyoming County (ies) Sublette, Lincoln

	River Values								
Segment	Water Quality	Relative Relief	Vegetative Cover	Scenic Setting	Unique Features	Land Use	Streamflow Characteristics	Wildlife Habitat	Major Recreation Activities
Green Riv. Lake & Warren Bridge	1	1	2	1	6,1,4,7,8	2	High in June & July	A-2,B-1	4,1,5,6.7
Warren Bridge To Fontenelle	2	3	8	2	4,5	2,4	Irrigation Diversion	A-2,B-1	4,1,5

Remarks:


Green River Lakes
Warren Bridge
Fontenelle Reservoir Headwater
120 miles